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TEAMDEC: INTEGRATIVE DECISION SOLUTIONS WITH MULTIPLE INFORMATION SOURCES

Virginia Tech

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Decision researchers have tended to focus on the characteristics of individual decision-making or of ad-hoc groups. In many applications, however, decisions are influenced by interactions among people who have specific skills and functions, and who may have an ongoing responsibility to the group. The functions of TeamDec are based on research that provides actionable insights about the unique nature of team-based decisions. To develop TeamDec, the contractor has integrated this research with recent developments in information technologies to provide software that improves decision-making in terms of decreases in time and resources required (e.g. personnel), and increases in the quality of decision outcomes. Because of the flexibility in design and the use of Java, with its reliance on interfaces to other software, TeamDec can interface well with other intelligent agents as part of a larger C4I infrastructure. It need not be used as a stand-alone tool.

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Overview

The rapid advances in computing technologies, combined with concomitant growth in digital information sources and the acceptance of digital content via technology, creates a need for decision tools that enable effective use of information. This need is not limited to any particular segment of technology users.

The amount and nature of Internet use has changed dramatically in the past few years. The estimated number of adult users in the United States increased 23% in 1998, to 53.5 million. In addition, the composition of the user base has broadened to include a wider variety of demographic profiles. Industry analysts conclude that the Internet is no longer viewed as a novelty, but as an integral way to accomplish daily activities. Not just a tool for business activities, the Internet is most frequently used to acquire and to communicate information, and for relaxation purposes.

The rapidly growing base of Internet users that reflects broad cross-sections of the general population, coupled with increasing levels of sophistication with Internet services and technologies, underscores the need and opportunity for developing flexible decision support software tools that enable users to accomplish two key objectives: 1) to acquire and integrate information from a vast array of sources, and 2) to develop effective processes for using the acquired information so that repetitive search activities can be accomplished simply and efficiently.

Decision researchers have tended to focus on the characteristics of individual decision-making or of *ad-hoc* groups. In many applications, however, decisions are influenced by interactions among people who have specific skills and functions, and who may have an ongoing responsibility to the group. The functions of TeamDec are based on research that provides actionable insights about the unique nature of team-based decisions. To develop TeamDec, we have integrated this research with recent developments in information technologies to provide software that improves decision-making in terms of decreases in time and resources required (e.g., personnel), and increases in the quality of decision outcomes. Because of the flexibility in design and the use of Java, with its reliance on interfaces to other software, TeamDec can interface well with other intelligent agents as part of a larger C4I infrastructure. It need not be used as a stand-alone tool.

Central to our objective has the implementation of research knowledge and technology in a manner that provides a decision support tool that can be applied across a variety of situations. In addition, the decision support tool should be consistent and reliable in the provision and integration of information appropriate for tailored scenarios, and provide decision structure driven by situation and available information, rather than by technological constraints. TeamDec, the decision support tool developed under this contract, can be used to obtain the following benefits:

- Augment team-based decision-making with an interactive structure capable of simultaneously incorporating input from appropriate functional areas,

- Enable dynamic decision-making with fewer people and more information by integrating information sources and media,

- Reduce decision errors in high-stress and time-sensitive operations by a) providing script guidance and b) providing simultaneous access to critical information,

- Facilitate efficient resource allocation (e.g., split base operations) through shared information sources with a virtual command center.

In the following section we describe TeamDec and its development in greater detail. Two scenarios are described to illustrate the dynamic capabilities of the software. We then describe the command and control channels that can be exercised through TeamDec. In subsequent sections we present the technical details of the software, and we provide information about the testing and performance observed with TeamDec users in a controlled, laboratory setting. The report also contains two appendices….the user's manual developed for TeamDec, and a copy of a master's thesis written by one of the graduate students who assisted in the software development.

1.0 Technical Approach

Sample applications

TeamDec can be used to help individuals or teams dynamically examine a wide variety of information sources and build decisions based on scripts. These scripts provide suggestions about possible actions (information sources, personnel to contact), based on similar instances of past actions that are stored in an information database. These scenarios, based on appropriately updated information, can be used for in-the-field decisions, as well as for training for stressful, time-sensitive, or infrequently occurring situations.

Scenario 1: Base Intrusion/Emergency Action Response

The command post controller receives a verbal report (via an audio link on his computer) from a mobile patrol. The patrol reports that an individual in a red shirt is lurking outside the fence. A kid wandering around or a possible terrorist attack?

The command post controller activates the "base intrusion" decision script with TeamDec. The audio report is integrated into TeamDec so that continuous contact is kept with the patrol.

TeamDec automatically initiates security alerting procedures. Simultaneously, TeamDec integrates the following information sources:

(a) a TeamDec audio/video link with security police/law enforcement commander,
(b) a window for the command post controller to type a short description of the situation.

The TeamDec window on the security police commander's desktop activates the base intrusion script as well (tailored to the SP's role). The SP commander also gets the audio link with the patrol. He brings up another audio link with a backup patrol.

Another window pops up on the TeamDec system on the command post controller's display. This window describes a terrorist attack by red-shirted individuals three hours previously, in England. The command post controller activates the "Probable terrorist" decision script in TeamDec, alerting the SP.

The "Probable terrorist" decision script now aids the command post controller in assembling the new response team and alerting the appropriate individuals.

Scenario 2: Humanitarian Mission/Logistics Response

The situation is an airlift to a city under siege. Food and medical supplies must be flown in, and critically wounded patients must be evacuated. The command post controller must schedule the night's flights into the city. Using TeamDec, he opens the airlift coordination script. Following the script prompts, the controller opens windows in TeamDec to check the pilot roster and available equipment. He opens a third window to

check the weather, both current and anticipated. Additional script elements prompt him to contact, via audio link, ground crews at the base and the target airfield, and the warehouse, to determine the amount of supplies that can be received. He is also prompted to check the status of military activity near the airfield and of civilian flights in the area.

The weather window provides an update that indicates that freezing rain may create delays. The officer alters the update facility to provide an update every 5 minutes, rather than every 30 minutes. Simultaneously, the controller contacts the scheduled pilots to advise them that flights will be moved up to avoid worse weather later.

The controller links to site personnel for landing instructions, and timing. Through the audio link with the supplying warehouse, he learns that the medical supplies to be airlifted in require special packaging and handling, in air and for ground transport. A prompt from the records database informs the officer about contacts, both local and distant, who can provide information and physical assistance handling hazardous and/or fragile materials. The officer links the ground personnel on the receiving end with the shipping depot and one of the suggested expert contacts, to facilitate shipping coordination.

Simultaneously, the contact at the target airfield advises the controller that two patients must be evacuated, and that they will require in-flight medical attention and medical equipment. The controller activates a script to prompt actions for medical evacuation procedures. The script advises the controller to contact available medical personnel at the base, and to do a search for nearby medical facilities with the needed equipment. Prompts then guide the search procedure and notification of the appropriate personnel determined based on search results.

With all aspects of the situation addressed, the controller checks the weather and notifies the pilots that the mission is to begin. The airlift script is completed when the controller has followed the prompts to contact the site personnel at the receiving warehouse to prepare for the planes' arrival.

In the following section we describe the capabilities of TeamDec in greater detail, and we provide a brief rationale for the software agent's components that builds on extant research in human and computer-aided decision-making.

1.1 Technical Discussion

Strategic Design and Function

Decision researchers have provided evidence of limitations and biases in human decision-making that are both social and cognitive in nature, and which are robust across a wide variety of situations. Limits to effective decision-making can be addressed by decision aids in several ways, including 1) making the task environment less complex, and 2) augmenting the information processing skills of the persons making the decision (Payne, Bettman & Johnson, 1993). TeamDec components incorporate both avenues for

improving decisions. TeamDec is a decision aid; it does not make decisions, but rather makes it easier to make good decisions in an uncertain and perhaps pressure-filled environment.

TeamDec is designed to minimize biases and limits on decision-making by providing structure to the decision and by augmenting human information processing abilities. The script capability is the heart of TeamDec. This database can be used to structure the decision in sequences of actions, and to suggest and provide sources of information for the content of the decision. This software enables a team leader to coordinate decision-making activities across personnel and distance.

TeamDec provides the following functions:

1. Decision structuring to determine appropriate information sources and team member participation by using

    a) scripts from a customizable script database, and
    b) prompts/queries about desired actions based on the script database that tracks and records previous information sources and personnel contacted from within a script,

2. Interactive, simultaneous communications among team members, for example, whiteboard technology, discussion groups, and video conferencing,

3. Real-time search and integration capability for information sources (e.g., leveraging commercially available search engines on the Internet and combining search results in a visual display),

4. Shared display capability, such that a screen structure and its content can be accessed by designated personnel, and

5. Automatic track-and-record feature to create a log of sources and personnel contacted from within TeamDec (for training and accountability, also used to update the records database).

A graphical model of TeamDec is provided in Figure 1.

TEAMDEC System Model

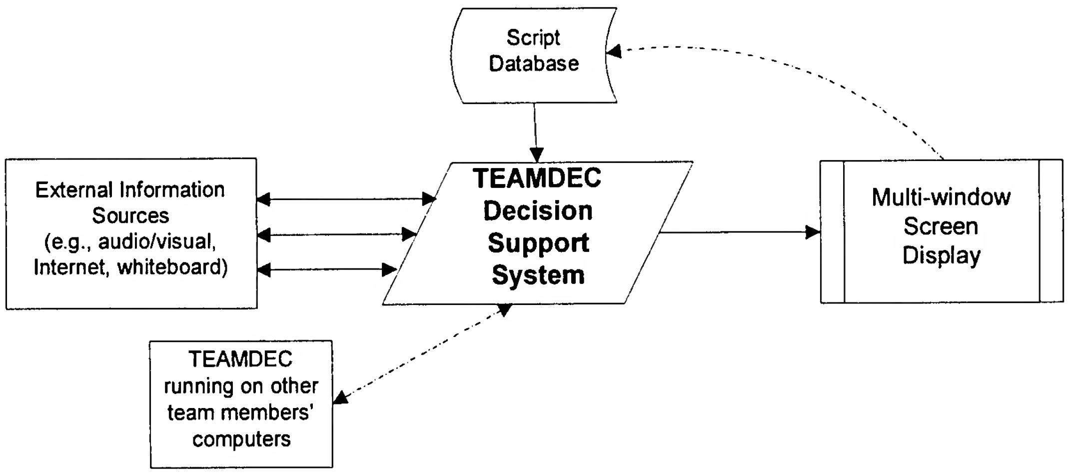

Figure 1

TEAMDEC Components and Rationale

In a simplified form, decision-making can be divided into two phases: 1) predecision processes, such as determining all possible alternative courses of actions and the consequences of each action (e.g., Keller & Ho, 1988), and 2) decision processes, such as restructuring available information (Coupey, 1994), and implementing an algorithm or heuristic for selecting a course of action (e.g., Billings & Scherer, 1988). Actions taken in each phase are influenced by characteristics of the task, such as the amount and complexity of available information, and by characteristics of the decision maker, such as the abilities, both perceived and actual, of the persons involved in the decision (c.f., Bowers, *et al.* (1993) for examples of decision bias due to tacit coordination among military pilots; Fischoff & Johnson (1990) for biases due to differences in problem conceptualization in *ad-hoc* groups).

Task and person influences can result in flawed decisions when the initial decision structure is not isomorphic with the situation. For example, people typically tend to be incomplete in their specification of the set of possible actions that could be taken (Gettys, 1983). TeamDec's script database can be used to insure that for a situation in which policies and procedures can be clearly delimited, the decision team is aware of all appropriate actions. In addition, the ability to fuse together information from multiple sources can also increase confidence that all appropriate information has been considered, and provide a back-check on the veracity of information when convergent data is obtained. The team leader can integrate multiple sources of data on the computer screen simultaneously, thus providing a clearer view of an operational situation.

A key element of TeamDec is the script database, which can be used to guide team decision-making. The script database enables a user to specify a set of

information/actions that should be taken, and to label this "script" with a scenario name. Then, when faced with the real situation (or for training), the user activates this script. This approach insures that the desired procedure is followed, that time is not wasted, and that a familiar environment exists. The ability to structure decisions in this manner can also reduce the risk that factors central to an effective outcome are omitted, that information is ascribed more weight than it should receive, or that different problem conceptualizations among team members negatively affect decision-making. Of course, once the script is activated, the user can request other actions to restructure the decision and use TeamDec as the situation unfolds. For example, the user could establish an audio/visual link with someone not indicated by the script. This flexibility enables adaptive decision-making for situations in which outcomes are uncertain and risk assessments are ambiguous.

With TeamDec, the team leader can contact other people and control the flow of communications between them. This facility can improve team-based decision-making by reducing or eliminating several social biases ubiquitous to many types of group decisions. For example, in team decision-making, a person who appears to have expertise or who is a charismatic speaker may dictate the formation of a set of actions that reflects his abilities or experience (McGrath & Altman, 1966). These actions, however, may not be most appropriate for the given situation (Larson, Jr. & Christensen, 1993). In addition, face-to-face communications increase the likelihood that decisions will be biased by the 'common knowledge effect,' (cf., Stasser & Titus, 1985) in which shared information receives greater weight in the decision process than it merits. This effect potentially constrains the set of options use as the basis for decision-making (McGuire, Kiesler & Siegel, 1987).

Within TeamDec, the team leader's ability to define scripts and to initiate contacts with intra- and extra-group personnel can reduce the possibility of disproportionate emphasis on one person or approach. TeamDec can also increase the number and quality of insights or options generated (e.g., through brainstorming, and by enabling the team leader to initiate communication with personnel in boundary-spanning roles (cf., Ancona, 1987). The ability to block communications among team members can also reduce the transmission of information that may bias decision-making, but without reducing the amount of information available to the team leader.

Through the "Action Advisor," TeamDec automatically accesses a database of user actions. TeamDec uses the database to "suggest" other actions to the user. This capability can help ensure that actions under pressure resemble those in more relaxed training environments. The database also provides a record of user actions that can be used as documentation, either for training or in operations.

In Figure 2, we provide two sample sequences to illustrate how TeamDec's functions could be invoked to assist in decision-making.

TEAMDEC Sample Procedures

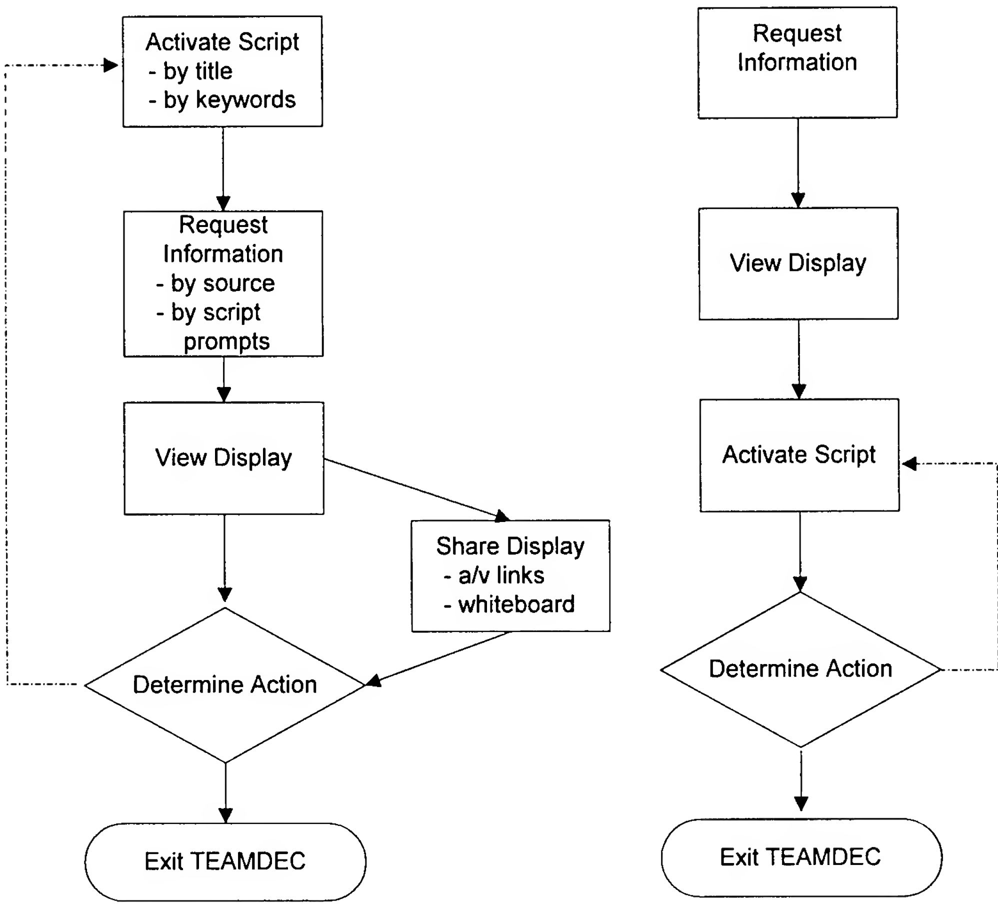

Figure 2

1.2 Technical Program Summary

The TeamDec software leverages commercial Internet technology. By using commercial Internet software extensively, we were able to accomplish the following objectives:

- reduce development time,
- increase reliability and functionality, and
- take advantage of rapid improvements in Internet software.

The use of commercially available technology also enhances TeamDec's across-application potential. For example, TeamDec could be used in business applications, such as product development, pre-launch product forecasting, and predicting competitor response. With TeamDec, a marketing team will be able to integrate multiple aspects of product design,

including knowledge of available technologies and current information about benefits/hazards of new materials, consumer needs, production capabilities, and regulatory constraints.

The heart of TeamDec is a Java applet. The choice of Java provides the following benefits:

- provides access to a growing library of applets and other Java codes,
- allows use of the increasingly high quality Java development tools,
- excellent software reuse and integration capabilities, and
- portability to nearly every modern PC and workstation.

This applet is responsible for managing the presentation screen, communicating with other TeamDec applets, manipulating the database, and interfacing to other Internet software.

The applet is designed to run within existing WWW browsers such as Netscape Communicator. By using these increasingly high quality, high-functionality browsers, we not only leverage large, ongoing software efforts, but we also gain significant multimedia capabilities in the form of plug-in software components.

2.0 Technical Development Description

2.1 Three-tier System Architecture

The TeamDec software implementation is organized in a three-tier architecture. TeamDec users interact with the system using a *client* program written as a Java applet. The clients communicate with each other as well as a main *application server* written as a Java application. All permanent information in the system, including scripts and user data, is stored in a database managed by a *database server*. The database server is a Commercial-Off-The-Shelf (COTS) server, mSQL, which communicates only with the application server using Java's interface to SQL. Any one of the many COTS database servers that use SQL will work with the system. The application server and database server have been run on both PCs and Sun workstations. Figure 3 provides a graphical representation of the communication links that exist in this three-tier architecture. Note that not all clients will communicate with other clients.

Communications Links in Teamdec's Three-Tier Architecture

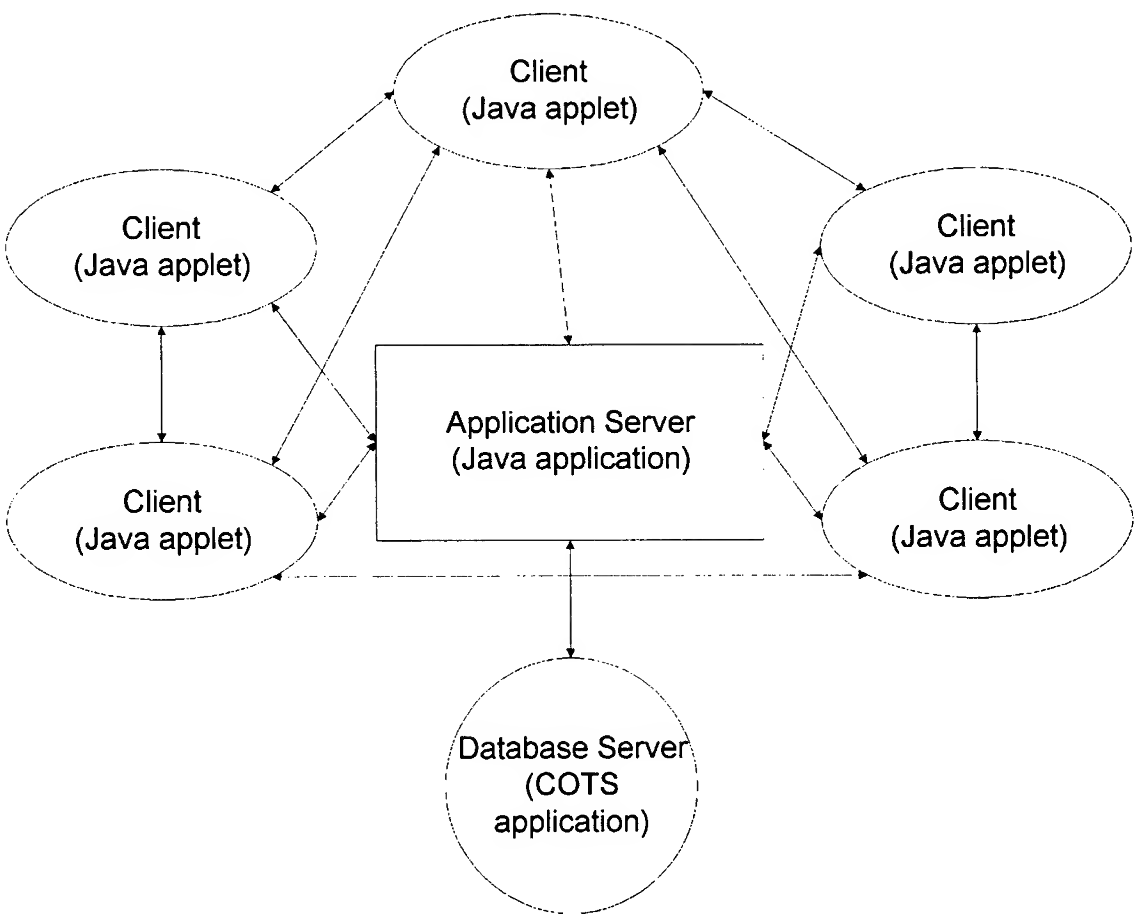

Figure 3

2.2 Leveraging Existing Software

The client applet provides the user interface, as well as many of the collaborative tools used in the TeamDec system. The philosophy adopted in designing and implementing the applet was to make use of COTS components wherever possible in the design. This strategy was adopted not only to leverage existing investments in software, but also to prove out the idea that the use of scripts in Internet software can be successful for a wide variety of software packages and actions. The applet makes use of components of Microsoft's NetMeeting program for video/audio conferencing. It uses Sun's Java Media Framework (JMF) package for playing a variety of video and audio file formats. Netscape's (or Microsoft's) web browser is directly controlled to display Web sites – further control can exercised by calling an experimental Web Java-based Web browser available from Sun. The package interfaces to several search engines, including common sites such as Alta Vista, Yahoo, and Ebay. Security is provided using the Sun Java Crytography Extension (JCE).

Some functions were not available in an "package" form or did not quite perform the actions that we wanted. These functions included a short "Send Notice" function, a group discussion function, and a whiteboard function that allowed Web pages to be annotated graphically and textually in a group format. Only the whiteboard required significant time to program. The main efforts involved in programming involved the implementation of the script capabilities and the communication between users (different applets).

Leveraging the COTS components was a successful strategy, but it was not without its headaches. We had to invest significant effort in evaluating the various packages available for each function followed by time invested in understanding the package well enough to use it within our framework. Perhaps the biggest hassle resulted from being an early adopter of many of the technologies. Because Java technology is rapidly evolving, we ended up using "buggy" beta versions of many of the software packages (or even buggy release versions...). However, the strategy will pay off long term as these packages continue to improve and add new functionality that TeamDec will use without additional effort.

2.3 Database Characteristics

All permanent files in the TeamDec system are stored as databases accessed via SQL. This gives significant flexibility in storage, access, and scalability. It also means that non-portable file formats are not part of the TeamDec code. Scripts, for example, are stored as a sequence of records. This allows us to use powerful, efficient search techniques that are part of commercial database packages. It also provides scalability because we could replace mSQL with, for example, a powerful distributed database server from Oracle. The use of a database format for storing, accessing, and searching for scripts is key to the TeamDec concept. User account files are stored in a database format as well.

2.4 Security Feature Implementation

Although not specified in the original contract, we decided to design security into TeamDec from scratch, rather than trying to add it in as we went. We tried to address basic issues such as user authentication, user authorization, and security of sensitive information. This was done via the use of the JCE package as well as through the three-tier architecture scheme. A nice feature of the three-tier architecture is that the database is "protected" from the outside world. All permanent information is stored in this protected database. The database server and its associated files can reside on a secure machine that only talks to the outside world via the application server. This allows for security of user account information as well as script information. It means that no user-level program ever directly accesses any of the database information. We relied on public/private key encryption schemes (supported by JCE) to authenticate users. We also designed the communication so that all applet-to-applet and applet-to-server communication could be encrypted using session keys built from the public/private key pairs. We did not, however, have the time or resources to implement the encryption other than as a test program. We are reasonably confident, however, that with the present design, TeamDec can become a secure distributed application. We plan to forward more details on TeamDec security in the form of a student thesis.

The only outstanding issue is the encryption/security of data with respect to outside packages. Two problems exist: (1) packages such as NetMeeting that handle their own peer-to-peer communication in unencrypted formats, and (2) communication with external Web pages and search engines in which the target system only receives information in plain text. We expect future solutions to this problem in the form of new software packages that will incorporate encryption, but do not see help in the immediate future.

3.0 Software Tests and Performance Assessments

Our testing activities were directed toward three objectives: 1) to assess the across-platform functionality of TeamDec; 2) to determine changes to the software to improve the human-computer interface, and 3) to assess the decision performance characteristics influenced by TeamDec use. While not required under the conditions of the contract, we believe that human subjects testing can provide with detailed, useful information about software performance. Our testing led to desirable changes to the interface, and to the detection and resolution of problematic aspects of TeamDec performance, thus resulting in a more user-friendly and effective software tool.

3.1 Platforms and Performance

The client applet has been tested and run successfully in two browsers, Microsoft Internet Explorer 4 and Netscape Navigator 4.5. It requires that the JMF and JCE packages from Sun be installed on the system. Further, we have written the applet in the Java 2 – the lastest version of Java – which currently is only supported as a plug-in in the common browsers. This plug-in must be downloaded and installed on a computer; this requirement is expected to go away as browsers support this new version of Java. There is nothing in these packages that prevents the clients from running on any platform. The only platform-specific aspect of the client is the audio/video conferencing – NetMeeting is only supported on PCs right now. The client is functional without NetMeeting, but it will not allow the audio/video conferencing function.

3.2 Human Subject Performance

A second focus of software testing involved human subjects. Very generally, our objectives were the following:

1) determine changes to the software to improve the human-computer interface,
2) assess performance effects on decision criteria that could be obtained by using TeamDec, and
3) extend the theoretical bases for using software such as TeamDec to guide and manage aspects of interactive decision making beyond information acquisition and dissemination.

To accomplish these objectives, we produced a training procedure for subjects that can be generalized for use by anyone beginning to use the software, and we designed and implemented experimental procedures and measures capable of gauging the nature and extent of the training needed to use TeamDec effectively. The latter effort result in the development of two testing instruments: a brief battery of multiple choice questions to assess objective knowledge of TeamDec, and a set of scales to assess subjects' perceptions of the software and of its effects on decision performance.

3.2.1 Testing Method

Analyses of human subjects using TeamDec were conducted in the Pamplin College of Business Behavioral Lab, at Virginia Tech. Thirty-five undergraduates completed the study for course extra credit. The study took approximately forty-five minutes to complete.

Subjects were welcomed to one of four individual rooms used for computer-based tests. The testing procedure began with an introduction to the purpose of the testing and the completion of a consent form. Subjects were then provided with a training sheet (see Appendix C) and informed that they could use up to fifteen minutes to become familiar with the TeamDec system.

Following the initial training, subjects completed a series of search activities in which the searches were conducted using TeamDec scripts, TeamDec actions (individually loaded script components), TeamDec search features, or web searches without TeamDec. Completion times for the task were obtained for all subjects. The mean completion times for the conditions were as follows: scripts, 24 minutes; actions, 27.6 minutes; TeamDec searches, 22.6 minutes; and web searches, 23.8 minutes.

Next, a random sample of subjects completed a brief battery of multiple choice questions about TeamDec functions. These questions assessed the amount of objective knowledge about the software acquired during the time-limited training phase. As a distractor task, subjects answered a series of questions about the information acquired in the search task.

After finishing the distractor task, subjects completed a series of scales matched to the functions assessed with the objective tests. These two instruments were used to measure over- and underconfidence in the use of TeamDec capabilities.

3.2.2. Testing Results

All subjects indicated that they had completed the training, following the instructions on the training guide, within the fifteen-minute time frame. No subject completed the training in fewer than ten minutes. Analysis of the responses to the objective knowledge questions indicates that over two-thirds of the subjects achieved 80% accuracy in their responses after the brief training. The remaining subjects attained only 60% accuracy. These results indicate that TeamDec is user-friendly, readily learned, and intuitively applicable to a variety of tasks.

To further determine how best to train people in the use of TeamDec's features, we examined data collected to enable assessment of confidence. In each of the questionnaires completed by subjects, questions were developed to reflect knowledge about the use of the scripting features, the communications features, and the search features. Our working hypothesis was that subjects would feel more comfortable using features with which they believed they had some level of prior familiarity. Thus, levels of confidence would be greater for communications

features than for the more novel scripting features, even though the ability to use the features was comparable.

An analysis of contingency coefficients was used to measure association between responses to the script and communications questions from the objective and subjective questionnaires. The analysis supported the hypothesis; subjects tended to exhibit overconfidence (subjective knowledge > objective knowledge) on the communications-related questions significantly more often than on the script-related questions ($\chi^2 = 7.22$, $p < .007$). To wit, no one exhibited underconfidence in his or her ability to use the communications features. In contrast, subjects split evenly between over- and underconfidence in their responses to script-related questions.

The response time measures for completing the task using different functions of TeamDec revealed no significant differences in the time needed to complete the task. This result was expected, because for a simple, repetitive search task, subjects were able to use the script and action features efficiently and effectively. The absence of an advantage, in terms of time savings, for script use is a function of the simplicity and repetitive nature of the training task, rather than a limitation of the software. We believe that for more complicated procedures (e.g., wider variety and/or greater number of actions), the script function would substantially reduce time to execute the search components of the decision.

The preceding results, considered together, suggest that caution should be exercised in the development of training procedures and in the assessment of their implementation. The potential for users to overweight knowledge about familiar aspects of software functions may lead them to limit the effort they invest in learning these aspects of the software, resulting – counterintuitively – in diminished ability to use the more familiar features of the system.

4.0 Commercialization Efforts

We have begun to investigate the potential for commercializing the TeamDec software. At present, we have disclosed the processes and functions of the software to the Intellectual Properties (VTIP) office at Virginia Tech. Based on a demonstration of the software and its capabilities, and on discussions about its unique features, VTIP has encouraged us to pursue a patent and to license the software.

VTIP has initiated the patent process. They have also developed a list of targeted opportunities for licensing the software. Primary targets include the major Internet service providers (e.g., AOL), browser manufacturers (e.g., Microsoft and IBM), large portal companies (e.g., Yahoo), and key database companies (e.g., Oracle).

Our goal is to see the ideas embodied in TeamDec adopted into commonly used, commercial software. We believe that this will provide the Air Force with the best, well-supported software with the TeamDec functionality.

5.0 Conclusions and Future Directions

Political and economic factors at both the global and the domestic level change rapidly and often dramatically. These events necessitate changes in the way Air Force resources are used to effectively accomplish a multifaceted objective of global dominance across a wide range of military operations. Success in attaining this objective will be achieved in part by updating the existing command, control, and communication infrastructure, employing new, computer-based technologies designed to augment decision-making capabilities. In this report, we have detailed the development of a decision support tool, TeamDec, which integrates information from different sources to facilitate decision-making in which a leader makes the decision with the input of a flexible team of people.

The use of the Internet as a dominant source of information makes software like TeamDec a useful tool for decision making. TeamDec provides the decision maker with the ability to automate the search for information across a variety of types and sources, and to track and record the results of complex search procedures. We believe that the focus of decision support software development should – and will – increasingly reflect a shift in the use of interactive information sources, such as the Internet. This shift represents a change in paradigm, from an emphasis on information search in a general, undirected, passive "surfer" approach, to a focused, task-specific, "searcher" orientation.

Although behaviors associated with specific goals for information search may not be mutually exclusive, we characterize search by Internet surfers as largely incidental in nature, with a tendency toward the acquisition of information that provides new knowledge. In contrast, people may use the Internet as a source of information for satisfying very specific activities (e.g., track the performance of a stock on a daily basis). For this latter category of activity, information search and use is more directed, with superordinate goals of developing procedures for information search that are reliable and readily repeatable.

TeamDec is a useful tool for decision makers, helping to minimize biases and limits on decision-making by providing structure to the decision and helping to overcome constraints on human information processing abilities. For example, the implementation of Teamdec allows actions such as searching the Web via several search engines, going to a particular Web page, starting a discussion board with several other users, sending a message to a user, and starting a video conference. One could easily imagine other actions including querying a database, buying a product, and activating an intelligent agent on behalf of the user.
In addition, the Action Advisor monitors the actions of a user, keeping track of the most recent set of actions. Based on those actions, it searches the script database for scripts that are similar to what the user is currently executing, and then presents the most likely scripts to user for possible execution. The capabilities enable a TeamDec user to search large information sources, to track the search results, to reliably repeat the search procedure when desirable, and to organize the search results to facilitate decision making.

As the paradigm shift toward a task-based orientation is widely recognized and implemented, however, changes in the use of large information sources and in the

technologies that make them readily available will necessitate the construction of more powerful decision support tools. For example, future software development may be effectively focused toward the extension of TeamDec's capabilities, with a goal of enabling newer software to guide decision making by constructing strategies, or alternative courses of action. The ability to delimit alternative strategies may be based on the software's ability to search databases using a goal hierarchy, present/display information based on importance weights, retrieve past strategies based on extracted characteristics of past and present situations, and assess the tradeoffs of alternative strategies. Such software development would be an important step in lowering the barriers that keep information from becoming knowledge, and knowledge from informing decision making.

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Appendix A

TEAMDEC Sample Screens and Capabilities

WHAT IS TEAMDEC?

Teamdec is a program that allows people to coordinate information from many different sources to make decisions. With TeamDec, you can make decisions using information from the Internet, files you have previously stored on your computer, or even through real-time communications with other members of your decision team. TeamDec can help you make better decisions more efficiently, whether working by yourself, or with input from members of a team.

Two unique aspects of TeamDec make it a flexible, useful decision tool. The program contains two databases, an action database and a script database. The action database is a set of stored tasks that you have completed. When asked, TeamDec records your actions and uses them to help guide your activities in subsequent decision situations.

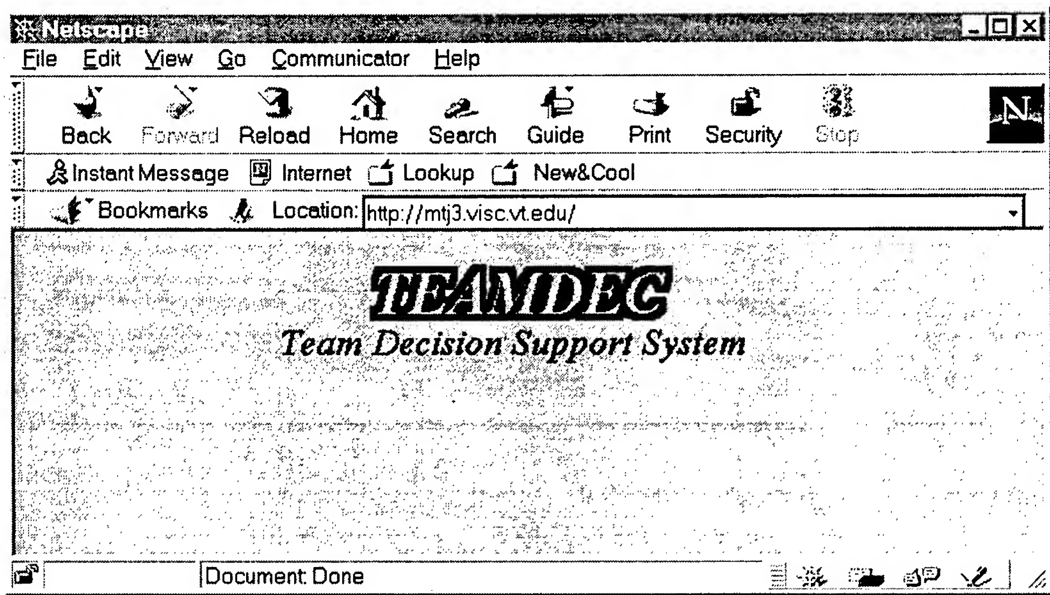
Whether working together or independently to manage decision making, team members can organize the actions they each take in making a decision in the form of scripts. These scripts can be kept on file in the script database for future, repeated use. Any team member can send a created and stored script to other team members.

On-line communications within a team are also possible with TeamDec; the program lets you define the communications group you need. To communicate with members, you can send notices (just like a memo), and you can hold discussions in a "chat room" type system. In addition, multimedia conferencing is possible with TeamDec. So, let's get started.

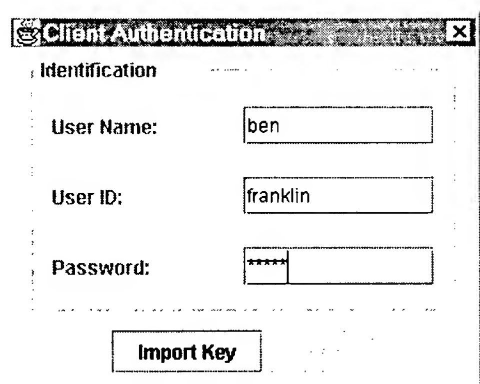
TEAMDEC: GETTING STARTED

Logging into Teamdec

To get started with Teamdec, open your web browser and go to http://mtj3.visc.vt.edu/.

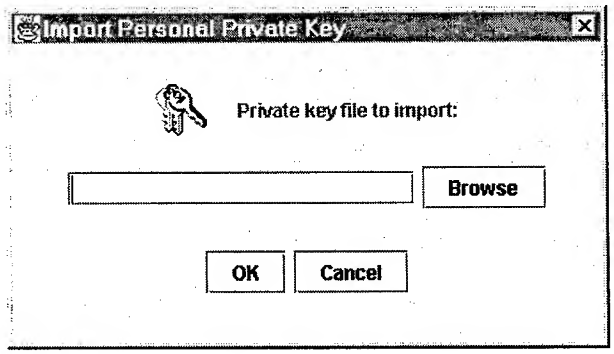


On the Client Authentication screen, enter your user name, user ID and password. Then click on Import Key.



You will be prompted to enter your private key information. The purpose of the key is to ensure that only the right persons have access to TeamDec and to register which person is currently in the system for identification and communication with other TeamDec members. More information on the encrypted key feature is contained in the appendix.

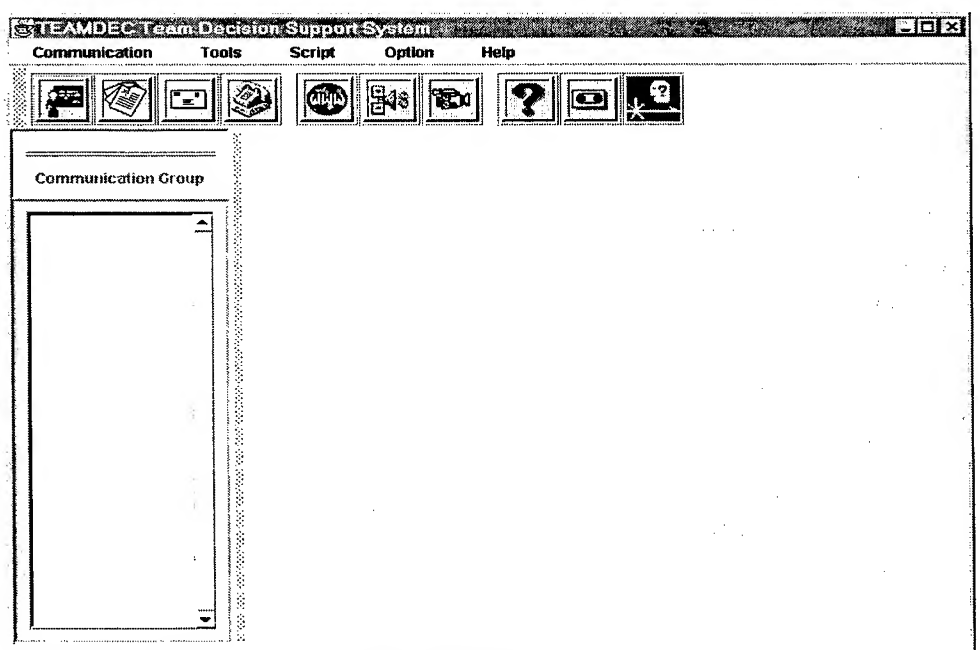
Next, you will see a new window, labeled "Import Personal Private Key." Now enter the location of your private key. For instance, if the file is located on the hard drive (your C: drive), and in a folder named "Authen" and a subfolder named "Keys" and the key name is "Key One.pvk," you would enter "C:\Authen\Keys\Key One.pvk". If the key is on a floppy, you would enter:A:\Directory\Foldername\Subfolder Name\Keyname. Then click on "OK."



You will return to the Client Authentication screen. Next, click on "Login." It may take a few moments to get into the system. You are now ready to begin using TeamDec.

Main screen

When you have successfully logged in to TeamDec, you will see the main screen. From this screen, you will be able to initiate any of the actions available in TeamDec.



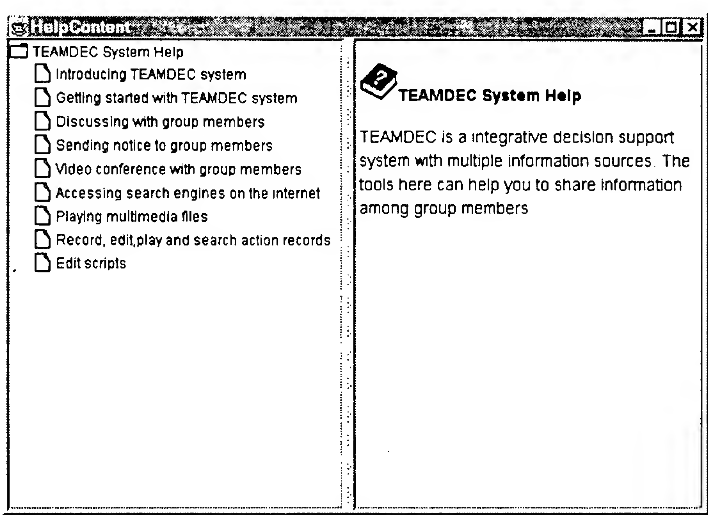
TeamDec's main screen contains all the options from which you may choose. These options are text headings at the top of the screen: "Communication," "Tools," "Script," "Option," and "Help." Clicking on the main headings will bring up a list of actions under that heading. The actions associated with each heading are provided in the following table.

TEAMDEC FUNCTIONS				
Communication	**Tools**	**Script**	**Option**	**Help**
Whiteboard	Select Communication Group	Edit/Save Recorded Data	Record Actions	Contents
Group Discussion	Open Browser	Load/Edit/Execute Scripts	Provide Suggestions	Manual
Send Notice	Search the Web	Start Script for Other User		About TeamDec
Video Conference	Play Audio			
Exit	Play Video			

Below the text headings are ten icons. From left to right, the icons are "Whiteboard," "Group Discussion," "Send Notice," "Video Conference," "Search the Web," "Play Audio Files," "Play Video Files," "Help," "Record," and "Support." You can select an action by either using the pull-down menu, or by clicking on the appropriate icon.

Online Help

Many questions you might have while you are learning to use TeamDec may be answered in the online Help section. To access this feature, simply click on the question mark icon on the main screen. When the HelpContent screen appears, move the cursor to the desired topic to highlight it, and then double-click to reveal detailed help.

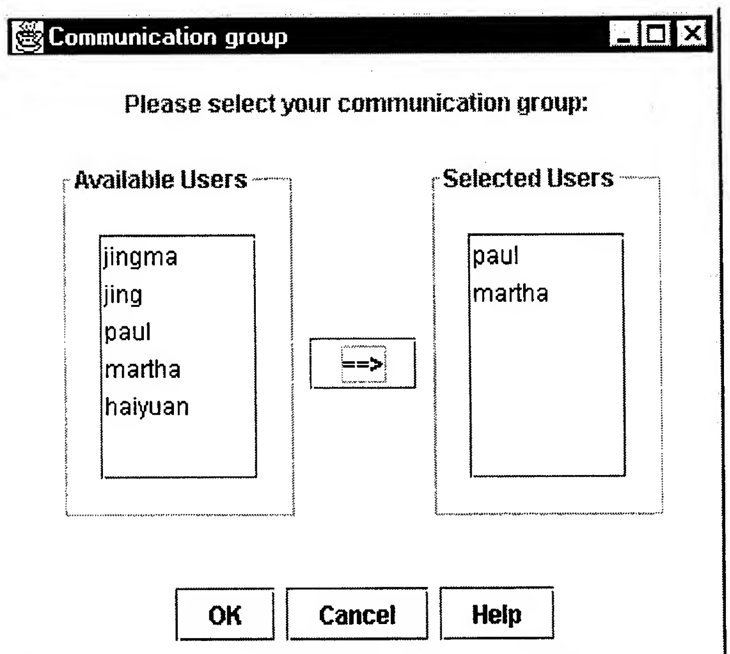


COMMUNICATING WITH YOUR TEAM

Group member discussion

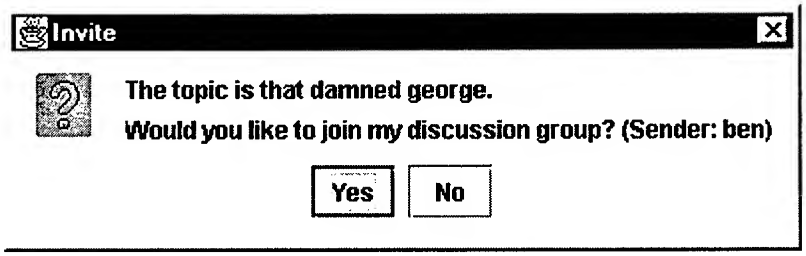
Communication is at the heart of TeamDec, and the group member discussion allows the different group members to interact with all other members of the team through text. Members can inform other members that a discussion is about to occur on a particular topic (such as "Designing air raid drill script") and can then have a discussion where all members get to have their input.

The first thing you will want to do is to pick your communication group members. On the main menu, select the "Tools" menu item. Then pick "Select Communication Group." On the "Select Communication Group" window, select the group members from your user list. Click on the arrow to send available users to selected users. Click the "OK" button to end the selection. The name of the group members you have selected will appear in the right frame.

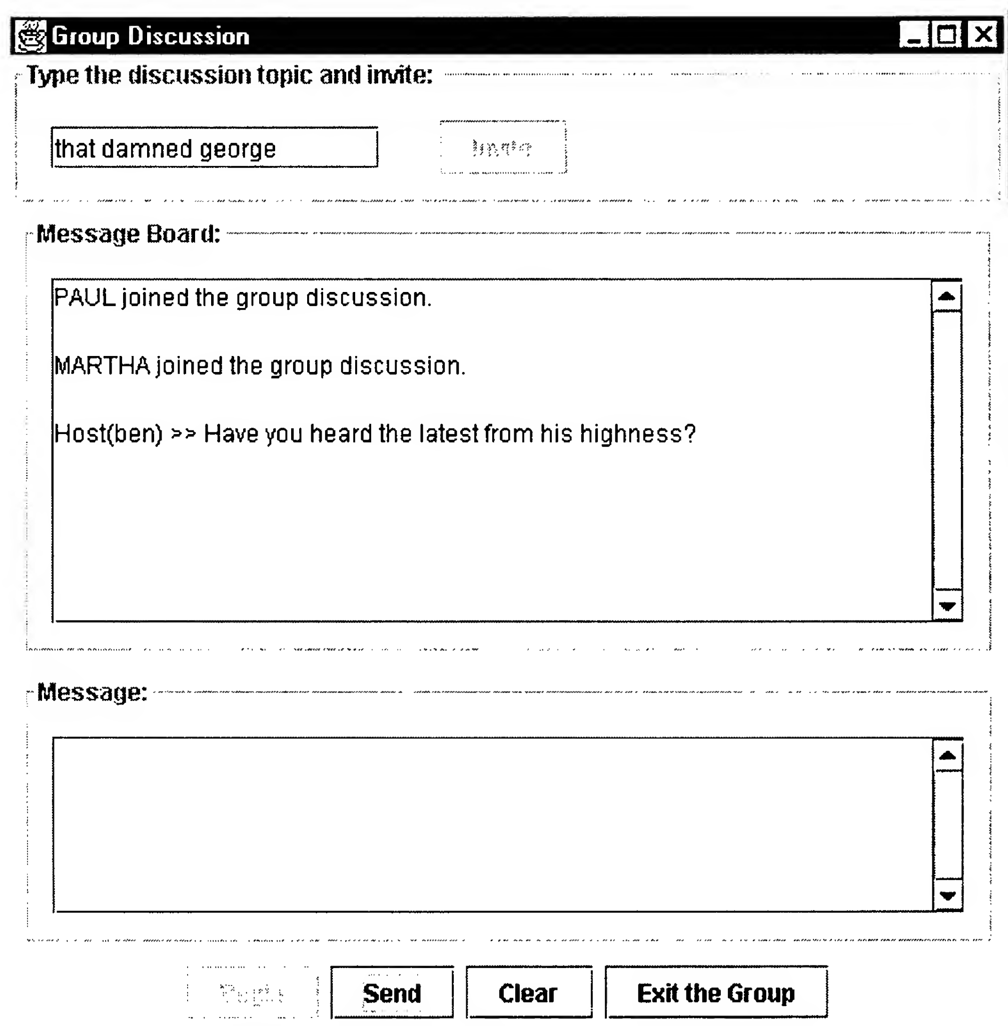


Now, you are ready to communicate with the persons in your group. On the main menu, select the “Communication” menu item, then pick “Group Discussion.” On the "Group Discussion" window, type your discussion topic on the "My Topic" field. Then click on "Invite" to notify your group members that a discussion is being held. Click "Begin" to start the group discussion.

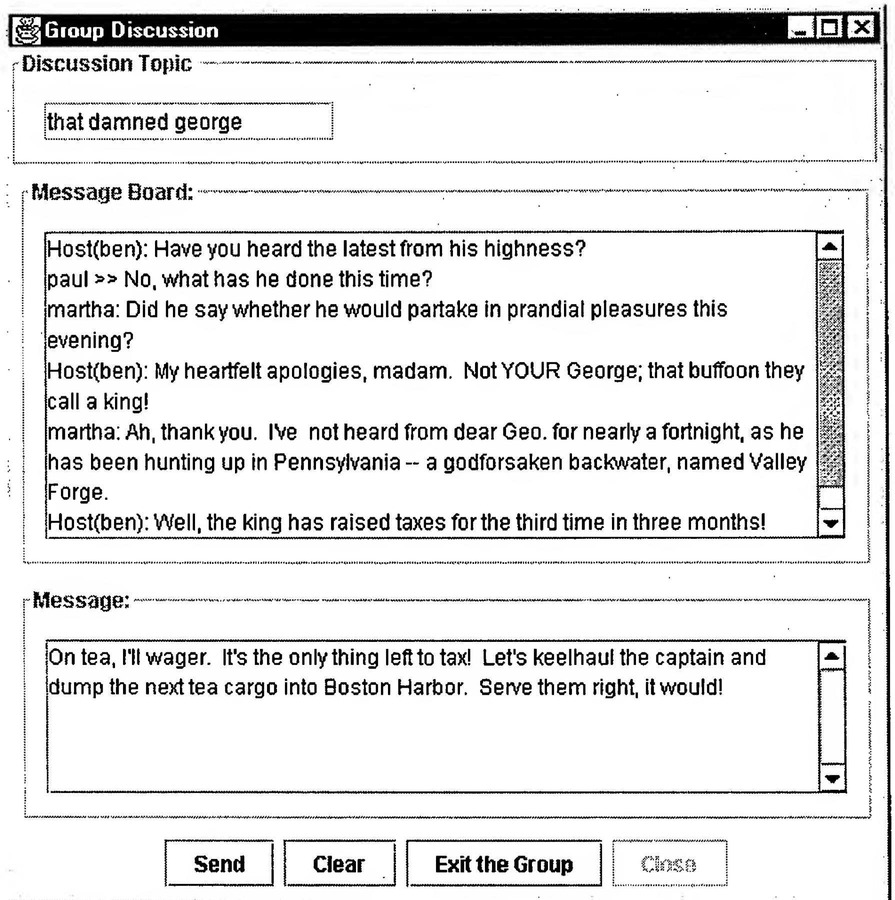
The invited members will receive a message with the option to join your discussion.



When a group member joins the discussion, you will be notified on your message board.

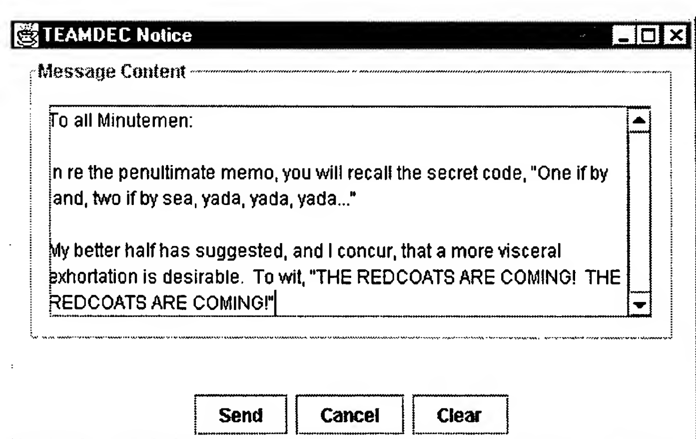


Type the message you wish to send on the "Message" field. Click on "Send" to send the message to those in your group. Click on "Clear" if you want to clear the screen display, erasing prior discussion. Click on "Exit the Group" to end the discussion.

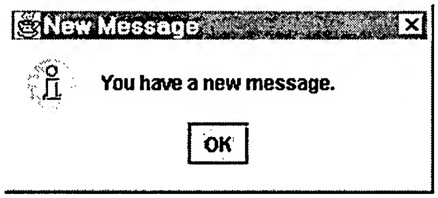


Sending notices to group members

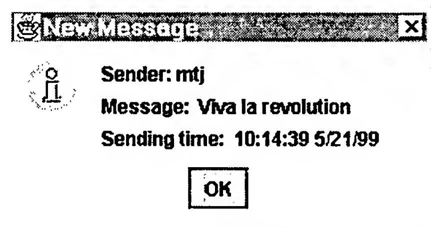
Sometimes you might wish to send a message to the people in your group without entertaining discussion. To do so, select the “Send Notice” option from the Communication menu, or click on the envelope icon on the main page. A notice screen will appear. Type in your message, then press “Send.”



When someone sends you a notice, you will receive the following message.



Press “OK” to accept the notice.



Video conferencing with group members

A video conference lets you communicate with other team members and actually see them on the monitor.

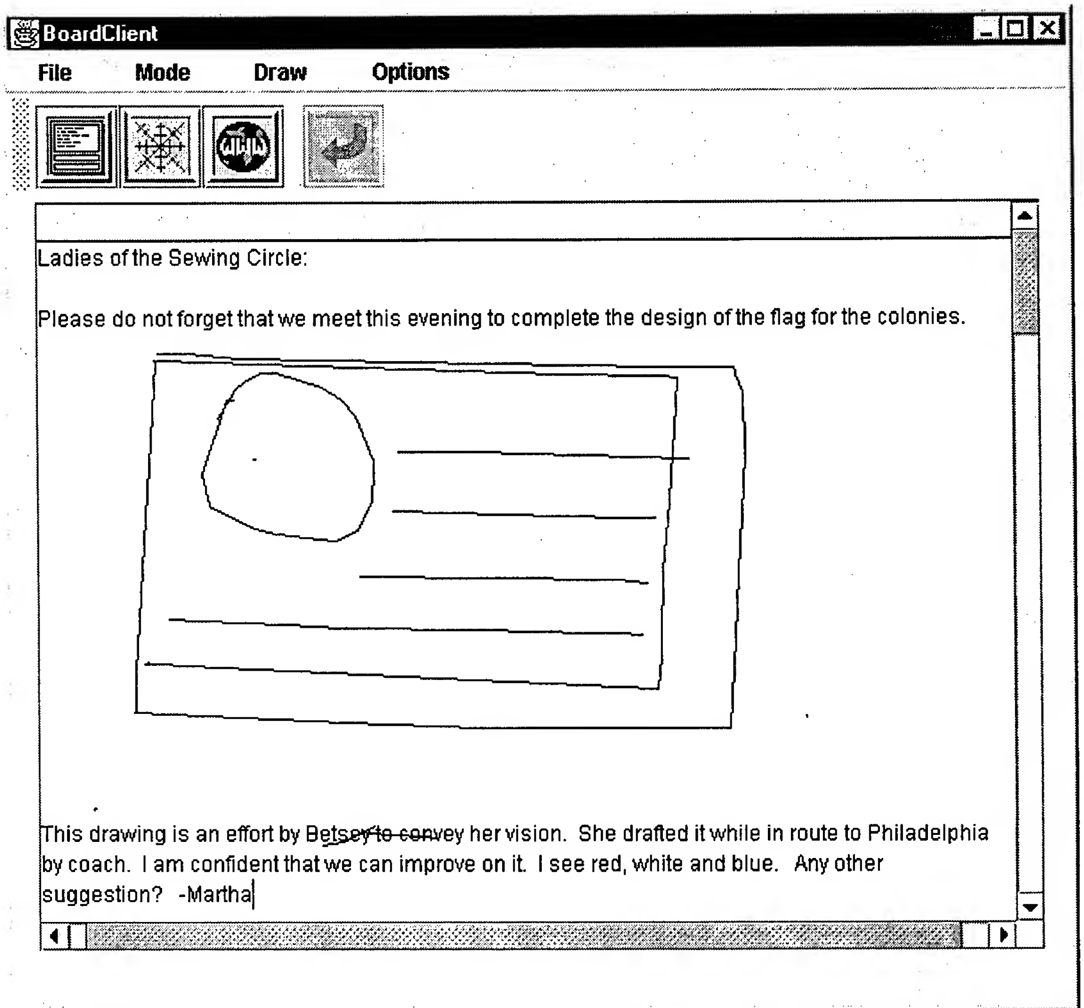
On the main menu, select “Communication,” then select "Video Conference" and then select "Call." On the video conference window, select the group members from the members list. Click "Call" to make the call. Click "Cancel" to cancel a call. At the end of the video conference, select "Video Conference" and then select "Hang up" to end.

Using the whiteboard

TeamDec contains an interactive whiteboard feature, useful for editing graphical displays with other group members. To use this feature, select “Whiteboard” from the Communications menu, or click on the board icon. On the board host screen, select “File” to choose whether you will open a file stored on your computer (“Open File”) or an image from a website (“Open Web Page”).

Once the file is open, you must select a mode for display. From the “Mode” menu, choose “Text,” “Graph,” or “Web,” as appropriate. The

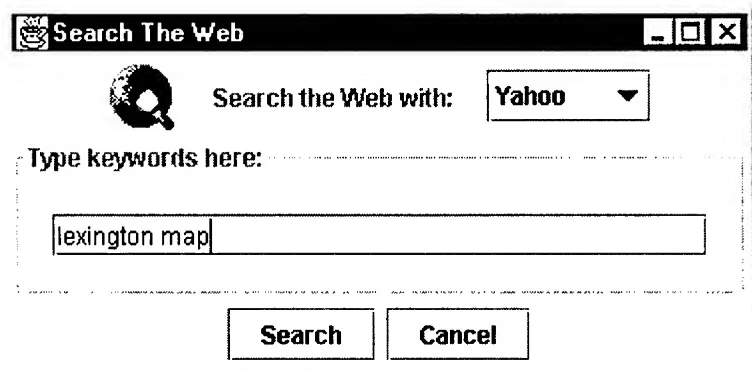
items under the "Draw" menu enable you to choose the graphical form in which you will edit the board image.



GETTING INFORMATION USING TEAMDEC

What about the Internet?

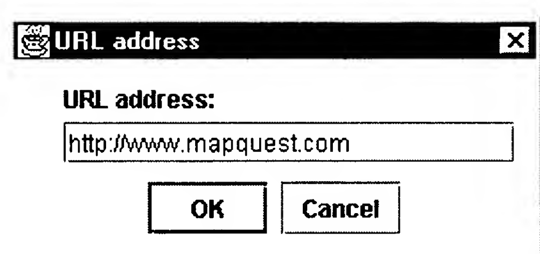
Accessing search engines on the Net with TeamDec is a snap. On the main menu, select "Tools" and then click on "Search the Web." On the next window, pick your favorite search engine from the drop-down list that will appear when you click on Yahoo. Type your keywords and click "Search" to get a list of "hits" which were found from your search. Clicking the "cancel" button will end your search.



If you already know the Web address you would like to visit, you can use TeamDec's Open Browser feature to go directly to that site, bypassing the need for a Web search.

To use this feature, go to the "Tools" menu on the main page and select the "Open Browser" option. On the next submenu, you must choose between a simple search and an advanced search. The simple search will store in a script (if the record option is on...) only the first site you visit. The advanced option will record a sequence of searches.

Once you have selected the appropriate option for your purpose, you will be prompted to type in the Web address, or URL.



Playing video and audio files

To play video or audio files, the first thing you have to do is locate the desired files. If a file is on the machine itself (a local file), select "Tools," then "Play Video" or "Play Audio." The Media Player will appear on the screen. Click "OK" to play the file.

Of course there's a whole world of video and audio files on the net that cannot fit on the biggest hard drive. For Internet files that you want to play with TeamDec, just type the URL address on the location field after finding the file you want to play. Then click OK. A list of the file types currently supported by TeamDec is contained in the appendix.

TEAMDEC'S ACTION AND SCRIPT DATABASES

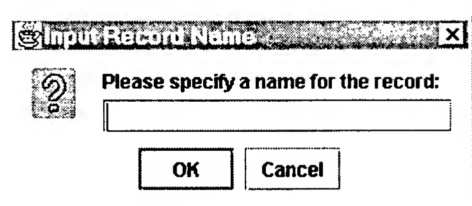
TeamDec has the ability to record actions taken by group members. This enables group members to look back on past actions and determine why a certain event was handled successfully or not with TeamDec. TeamDec's Action Advisor function also uses information about stored actions to develop appropriate action suggestions.

Creating and storing scripts

A TeamDec script is a sequence of actions that, once initiated, can be used to guide your activity in a particular situation from beginning to end. A well thought out script can eliminate errors that might occur in situations if the actions to be taken were not planned beforehand. Scripts can also make decisions more efficient, through streamlined actions that eliminate unnecessary activity and to store series of decision activities that will be used repeatedly.

To record the actions for a script, select "Option" from the main menu. Then click on "Record Action." Select "On" from the submenu. The record icon will appear in the left frame. Every action you make from this point on will be recorded. To finish recording, select "Option" on the main menu, then "Record Action," and "Off" on the submenus.

To edit and save recorded actions, select "Script," then "Edit/Save Recorded Data." On the following Record Edit window, a newly created record will appear in the record list view without a name. Click on "Save." An Input Record Name window will appear. Type in your desired script name, and click "OK" to save the record.

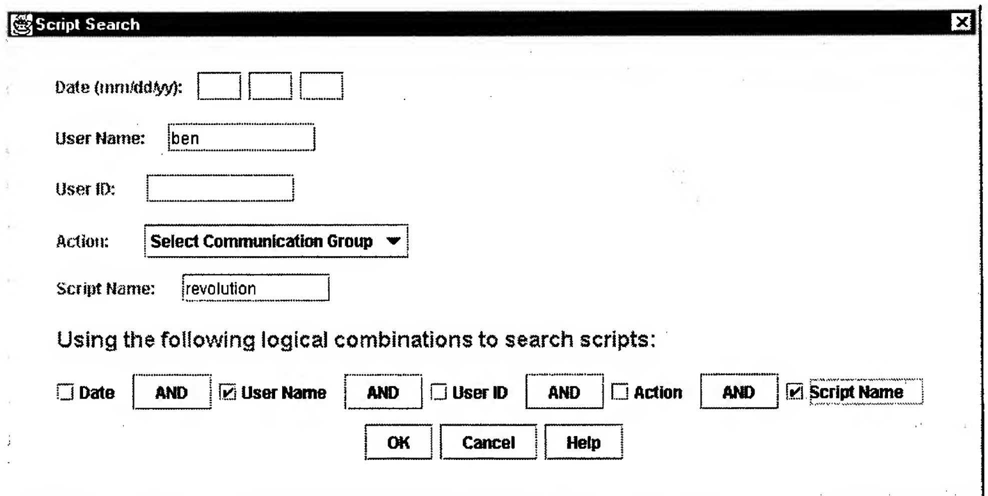


The name you have chosen will then appear to the left of all selected records, under the heading, "Record Name."

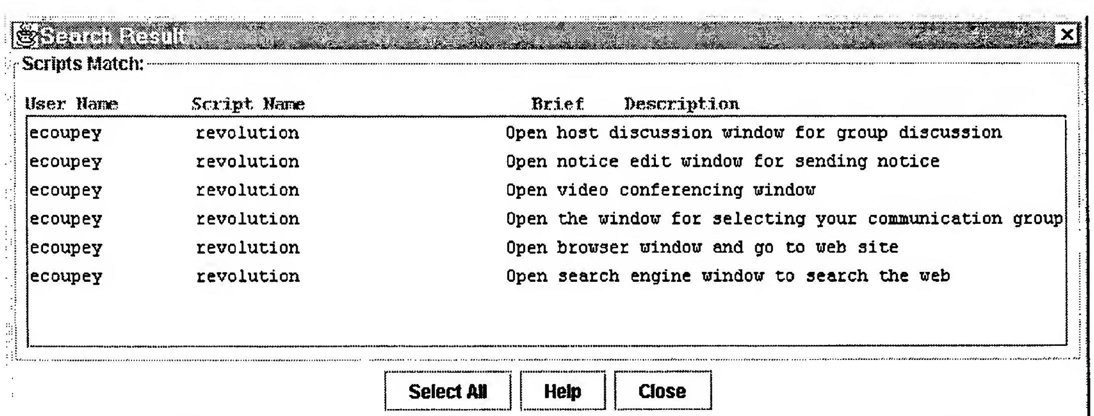
Starting a stored script

To edit or execute a stored script, open the "Script" menu on the main screen. Then select "Load/Edit/Execute Script" from the submenu. Next, select "Script" and then "Load" to get to the script search screen. You can find a previously generated record by searching for the date it was created, the user name, user ID, action, or the record name. Just click on the desired buttons to include more or less data in the search. You must also designate the appropriate logical combinations at the bottom of the screen to initiate your search. For example, if you search by user name and script name, then you must click on both "User Name" and "Script Name" to complete the search.

When you have entered the necessary information, press "OK" to perform the search, or "Cancel" to end the search.



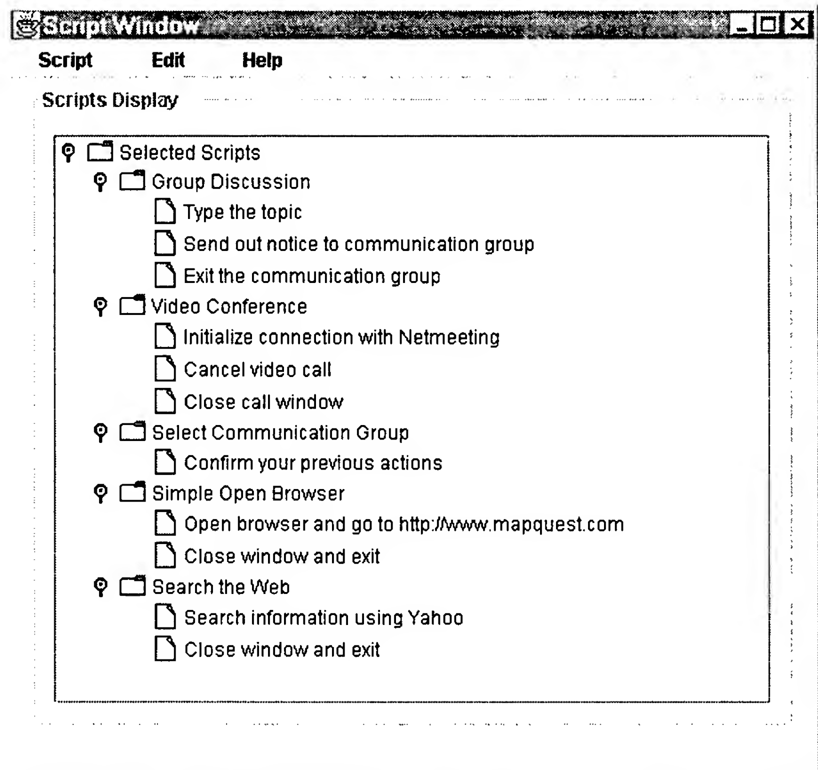
When the search is completed, you will receive a script display window. This window contains all of the recorded actions that meet your search criteria.



Editing and running displayed scripts

To edit or run your script, select “Script” from the main menu. Then click “Load/Edit/Execute Scripts.” Next, select “Script” and then “Load” to get to the script search screen. In the following Search Result window, select “Select All” to load all of the retrieved scripts, or highlight individual records.

Scripts are listed in a tree view after loading. When you double click on an item, a window will appear with detailed information about that item. If you decide that an item is not necessary for your script, simply highlight that item, and then click on the “Remove Selected Item” submenu, under the “Edit” menu.

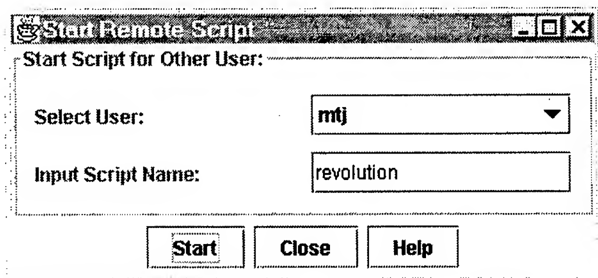


After editing the script, pick "Script" and "Reload" to reload the original scripts. On the script window, select "Script" and "Save" to save the script. You can pick "Script" and "Execute" to execute all the scripts at once.

Remote Scripting

Through the Remote Script facility, you can send a script to other team members to execute. Thus, the script function can be used to facilitate training in situations where efficiency and standardization are desired.

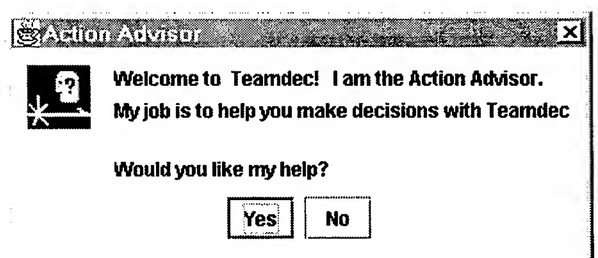
To use this feature, go to the Script menu on the main page, and select "Start Script for Other User." Type in the desired script name, and click on "Start." The other user will receive a message to ask whether s/he would like to run your script.



Teamdec's Action Advisor

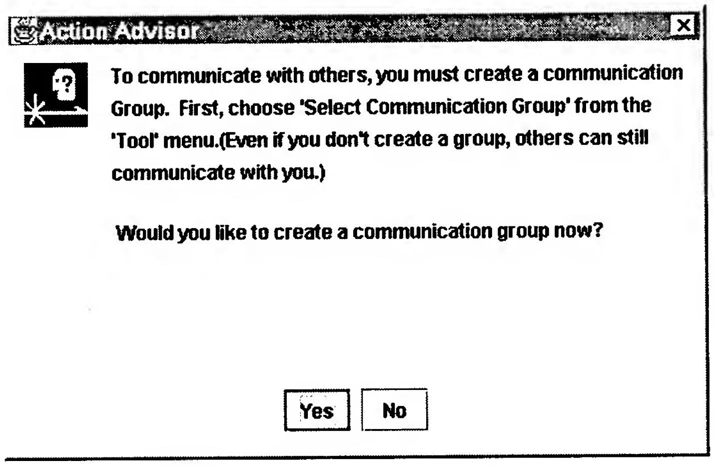
The Action Advisor can provide you with information to help you make decisions. For example, it can suggest previous actions completed by you, or by others in your team, that seem related to your present activities.

When you start up TeamDec, you will receive a welcome screen, asking whether or not you would like the Advisor's assistance.



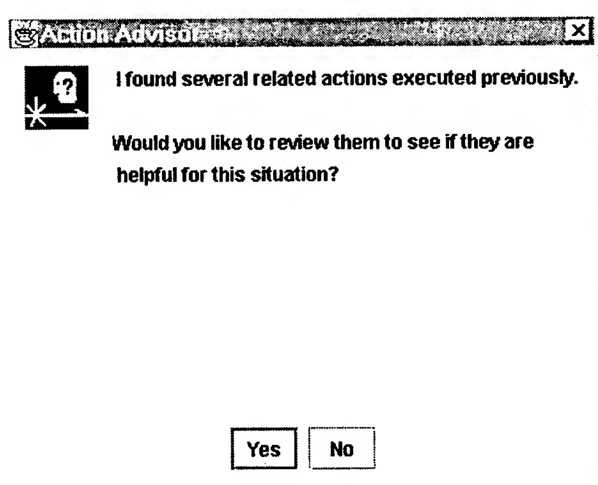
Just choose "Yes" or "No." If you select "No," you will receive no further messages during your TeamDec session. If you select "Yes," then you will be prompted to set up your communication group.

As always, it is your choice as to whether or not you wish to act on the Advisor's suggestion.

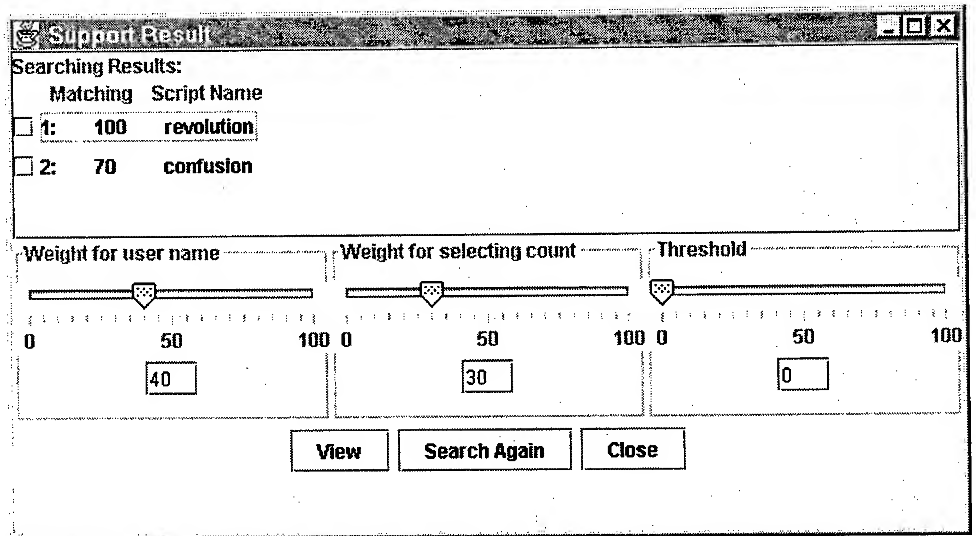


If you choose "Yes," the Advisor will assist you in setting up your group.

Once you have begun your TeamDec session, the Action Advisor will appear only when you have initiated an action for which there is a previous history, stored in one of the TeamDec databases. If this happens, you will receive the following message.



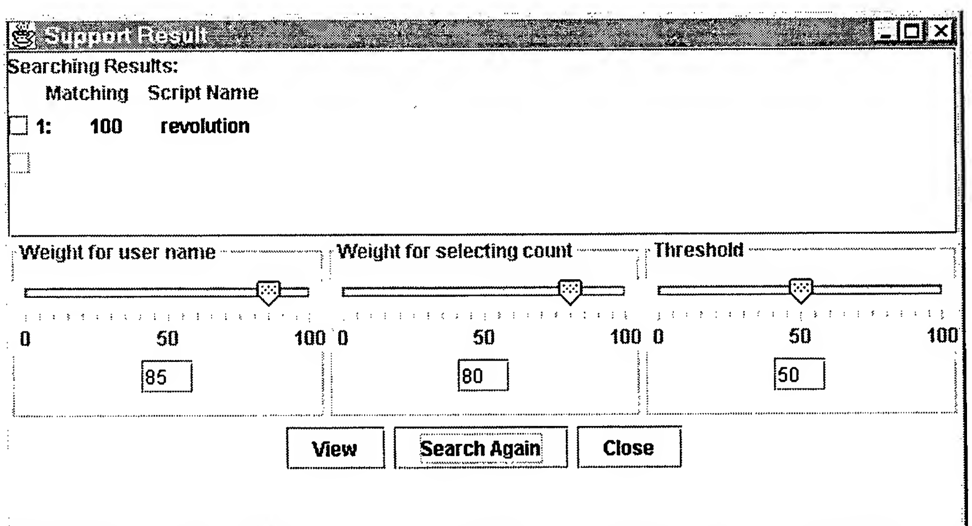
Again, the choice is all yours. If you choose "Yes," the Advisor will produce a Support Result screen. This screen will contain information about the stored actions that appear related to your action.



On this screen, you can adjust the criteria that you would like the Action Advisor to use in making suggestions about appropriate actions. For example, you can tell the Advisor that you only want input about the related activities you have stored. To do so, move the weight for user name to 100.

You can also indicate a preference for actions that have been carried out frequently, simply by adjusting the weight for selecting "count." The threshold criterion is used to place additional constraints on the extent to which the actions that match your criteria are acceptable.

Once you have indicated your selection criteria, select "Search Again." The results will be displayed in a new Support Result window.



Now you know the basics, you're ready to make decisions with TeamDec.

Appendix B

Security Architecture for the TEAMDEC System

Haiyuan Wang

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science
in
Electrical and Computer Engineering

Mark Jones, Chair
Eloise Coupey
Scott Midkiff

July 7, 1999
Blacksburg, Virginia

Keywords: Network Security, Cryptography, Authentication, Digital Signature, Key Agreement, Java, TEAMDEC

Security Architecture for the TEAMDEC System

By

Haiyuan Wang

Mark T. Jones, Chairman

Department of Electrical and Computer Engineering

(ABSTRACT)

The prevalence of the Internet, client/server applications, Java, e-commerce, and electronic communications offers tremendous opportunities for business, education and communication, while simultaneously presenting big challenges to network security. In general, the web was designed with little concern for security. Thus, the issue of security is important in the design of network-based applications. The software architecture proposed in this thesis allows for the secure and efficient running of a team-based decision support system, specifically TEAMDEC. Based on the system's requirements and architecture, three types of possible attacks to the system are identified and a security solution is proposed that allows for user authentication, secure communication, and script access control. The implementation of these features will reduce security risk and allow effective use of the valuable system information data.

Acknowledgements

I am deeply grateful to my advisor, Dr. Mark T Jones, for his continued guidance and support throughout this work. Dr. Jones's extensive knowledge and creative thinking were truly invaluable.

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Finally I want to express my gratitude to my husband, Yu Wang, who gave me his love and emotional support during the past years.

TABLE OF CONTENTS

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Chapter 1 Introduction

1.1 Introduction

The growth of the Internet and the World Wide Web (WWW) during the past few years has been dramatic. Most business and government institutions have their own web pages, and web browsing is quickly becoming the primary source of information for people of all ages. Current estimates indicate that there will be 500 million users connected to the Internet by 2001[1]. The prevalence of the Internet, client/server applications, Java, e-commerce, and electronic communications offers tremendous opportunities for business and education, while it simultaneously presents big challenges to network security because cyberspace is an open, distributed, and insecure environment. An organization's key asset, business information, becomes exposed and more vulnerable. If no security measures are taken, unauthorized access to this information is easy to obtain and difficult to detect. In this expanding electronic world, security issues take on new importance and complexity. Enforcing security in such a complex environment requires a security model and administration. Unfortunately, the web was designed with little concern for security. Thus, the issue of security is essential to network-based application.

The software architecture proposed in this thesis allows for the secure and efficient running of a team-based decision support system, specifically **TEAMDEC**[2].

1.2 Overview of TEAMDEC

TEAMDEC is an intelligent decision support tool that allows people to coordinate information from many different information sources to facilitate decision-making. People can make decisions using information from the Internet, or from scripts previously stored on the database, or even through real-time communications with other members of the decision team. A key element of **TEAMDEC** is the script database, which can be used to guide team decision-making. The script database can be used to provide suggestions about possible actions (information sources, personnel to contact) based on similar instances of past actions that are stored in the action database[3].

TEAMDEC can be used to help individuals or teams make better decisions more efficiently, whether working alone, or with input from members of a team. The security challenges arising from these features are substantial.

The following are the main requirements influencing the security architecture for **TEAMDEC**:

(1) **TEAMDEC** is for military use. It demands a higher level of security than a simple cooperative system. Thus, to guarantee that only an authorized user can access **TEAMDEC**, user authorization should be based on strong cryptography rather than on a simple password-based authentication scheme.

(2) To provide guarantees of the integrity and the secrecy of scripts in **TEAMDEC**, there is a need for fine-grained access control to individual scripts and their attributes. Thus a generic access model is required that enables access rights to be based on an individual's role in the system.

(3) **The TEAMDEC** runtime environment involves dynamic user groups. In such an open environment, communication among group members must be secure and, at the same time, efficient. Authenticated key agreement protocol based on the Diffie-Hellman[4] method can be employed to achieve that purpose.

1.3 Thesis Statement

1.3.1 Objectives of Research

Due to the sensitivity of the data related to decision-making, especially before a final decision is reached, security has been one of the main concerns of **TEAMDEC**. These issues demand a systematic response to making safe and controlled access to **TEAMDEC** along with its significant information - scripts. Thus, appropriate security mechanisms should be identified in order to maintain the confidentiality and integrity of system data. The research focuses on implementation of a security architecture that will provide the following security functions:

(1) user authentication by using public key cryptography that offers powerful tools for proving identity,

(2) role-based, fine-grained access control model that provides a finer level of security control for individual scripts, and

(3) authenticated key agreement protocol based on Diffie-Hellman[4] for safe communication among team members.

1.3.2 Contributions

First, the focus of this research is on how to develop a high quality Group Decision Support System(GDSSs). Qian Chen's research investigates the use of GDSSs as a practical aid for an organization and concerns with the factors influencing the quality of an interactive software system and concentrates on the design of interactive GDSSs. Based on the theories and concepts of human decision-making, the design principles of interactive software and GDSSs are applied to the development of **TEAMDEC**. Several concerns are taken into account, primarily including usability, efficiency, effectiveness, and security, and these concerns influence the quality of **TEAMDEC**[2].

Second, the desired collaborative features of **TEAMDEC** have been implemented. These features include interactive, simultaneous communications among team members of **TEAMDEC**, for example, group discussion and videoconferencing functions. Real-time search and integration capability, for example, retrieving search results from commercial search engines on the Internet and displaying them. The most important contribution is that the implementation of **TEAMDEC** script system. The system is able to record and track the user's actions and provide the action suggestion scripts and thus improve quality and efficiency of decision-making. All these features are necessary functions in group decision support systems

Third, the contribution of this thesis is that the security architecture is proposed and implemented. These security features enable the secure operation of **TEAMDEC**. The proposed security features include user authentication to prevent unauthorized access, encryption/decryption mechanism based on the Diffie-Hellamn[4] key agreement

protocol for safe communication among decision team members and script access rules to maintain the confidentiality and integrity of system data.

1.4 Thesis Organization

The thesis is divided into the following chapters. The first chapter begins with an introduction and overview of **TEAMDEC** along with relevant security issues and identifies the security architecture. It then gives the thesis statement and organization. The second chapter first gives an introduction to the objectives of network security. It then reviews literature on areas such as a user authentication system, cryptography and access control. The advantages and disadvantages of different algorithms and protocols are also examined and compared. At the end of this chapter, new security features of Java are reviewed. Chapter Three provides an overview of **TEAMDEC** and its architecture, then gives a detailed security requirement analysis of **TEAMDEC**. The analysis involves the examination of security objectives related to confidentiality, integrity, and availability. It then defines three types of attacks and provides the proposed security architecture. The fourth chapter goes into more depth on the implementation of the security architecture of **TEAMDEC**. Topics include user authentication, data encryption, and script access rules. The evaluation of the security implementation is presented in chapter five. The analysis is based on two factors: computation speed and the ability to prevent different attacks. In addition, the advantages and disadvantages of the security algorithm are evaluated. The chapter concludes with a brief discussion of the possible improvement in the future. Chapter Six provides conclusions and closes the thesis.

Chapter 2 Review and Background

This chapter presents a review of some areas in network security. The chapter begins with an overview of network security. It then moves into user authentication and cryptography and presents some of the algorithms and protocols, such as public key cryptography and digital signatures. It continues with a review of access control and database security. Finally, new security features in Java are discussed.

2.1 Overviews of Network Security

2.1.1 Objectives of Network Security

With usage of the Internet and Intranets, today's networks are complex and diverse. This diversity, both technically and geographically, means that network security becomes a critical, ongoing issue for an information technology environment. System data and other sensitive information are exposed to threats such as unauthorized access, unauthorized modification, or unauthorized denial of services. Following are a few fundamental objectives of network security [1].

(1) Integrity

Integrity ensures that data is transmitted from the source to the destination without undetected alteration [6]. For example, if one wants to load a script from the database in **TEAMDEC**, one wants to be assured that the script is exactly what is wanted and has not been altered by a third party.

(2) Confidentiality

In communication, confidentiality requires that the intended recipients know what was being sent but unintended parties cannot determine what was sent[6]. For example, when a user shops online, he must ensure that his credit card information must be kept secret when transferred over the Internet. Other examples include critical business information or personal data covered by privacy laws. Mechanisms commonly used to provide confidentiality are authentication[5] and encryption[6]. For example, "*Hello, world!*" can be encrypted to "*xyOoLnWOH0eqRwUu3rQHJw*" by using a specific key[7].

(3) Availability

Availability ensures that the authorized users of the system will not be denied access when access is desired. An online stock trade system must be accessible to the investor when the stock market is open.

In addition to the fundamental objectives addressed above, several other objectives are frequently mentioned including accountability and disaster recovery. Accountability ensures that managers can determine who made what changes, when, and from where[1]. Summing up, these objectives provide the needed foundation for network security.

The proposed software architecture for **TEAMDEC** uses public key-based user authentication and data encryption to ensure data confidentiality, and uses role-based script access rules to ensure data integrity. All these schemes are used to achieve the objectives of network security.

2.1.2 Threats to the Network System

As the computer networks and distributed systems expand, they not only offer endless opportunities, but also create a number of threats. The threats are increasing as fast as the growth of the networks. Some threats are mainly due to people who deliberately try to steal critical information and secrets or simply change data. Others are virus threats and physical threats[1]. Each of these types of threats is discussed below.

2.1.2.1 People Threats

People threats usually include unauthorized use, deletion, and/or modification of system data. Some people are hackers who are motivated by the desire to break into secure systems. The most common form of access is through repeated login attempts[5][8]. The other biggest threat is when an individual of an organization supplies information (like account details) to a hacker in order to obtain confidential information. Using password protection often prevents the normal hacker. Using encryption schemes can provide more secure protection. These schemes will be discussed in detail later in this chapter. In TEAMDEC, to provide system data confidentiality and integrity, public key based user authentication and script access rules are employed to prevent people threats.

2.1.2.2 Virus Threats

Computer viruses are the most widely recognized example of a class of programs written to cause some form of intentional disruption or damage to computer systems or networks[1]. A virus is a piece of programming code inserted into other programming to cause some unexpected and, for the victim, usually undesirable event[9]. Viruses can be

transmitted by downloading files from other web sites or by files on a disk. The source of the file being downloaded or received is often unaware of the virus. The virus lies dormant until circumstances cause its code to be executed by the computer. Some can be quite harmful, erasing data or causing the hard disk to require reformatting. The best protection to prevent a virus is to know the origin of each program or file you load into your computer. Typically anti-virus software can help to remove any viruses that are found.

2.1.2.3 Physical Threats

Physical threats usually originate from the physical environment. They can include electrical power failure, hardware failure or environment failures that cause damage to the whole system. Possible consequences include loss of system data, data integrity, and/or interruption of services[1].

To achieve secure and reliable operation of the network system, the threats to the system must first be identified and adequately addressed. Otherwise a threat, whether of natural causes or the result of human behavior, may cause substantial harm or loss to the whole system. The proposed security architecture for **TEAMDEC** is mainly used to prevent people threats. The following discussions give a review of different schemes to act against people threats.

2.2 User Authentication

The user authentication system is the first line to prevent unauthorized users from gaining access to the system. Authentication is the process of reliably verifying the

identity of someone and ensuring the person is who he claims to be and not an impostor. Some authentication systems are accomplished with the use of a password that must be presented to the system. Other authentication systems require the user to present a physical key or physical characteristics, such as fingerprints. There are lots of examples of authentication in our everyday life:

(1) By presenting the student ID card, the student is authorized to enter the VISC lab at Virginia Tech.
(2) At an automated machine, you identify yourself using your ATM card. You must input a personal identification number (PIN) to authenticate yourself.
(3) An online order company might accept as authentication the fact that you know the expiration date on your credit card.

2.2.1 Authentication Objectives

By providing only authorized users with an authentication to access the system, unauthorized users have no means of access. But this does not mean that unauthorized users are unable to gain access to the system because the system does not authenticate the identity of a user, but who the user claims to be. That is, unauthorized users are able to access the system by appearing to the system as an authorized user.

Authentication is tremendously important in computer and network applications. The other party you communicate with may be in the next room or another city. You have none of the visual or aural clues that are helpful in everyday communication. Since the system cannot verify the user's true identity, measures must be taken to defend the

system. That is, the primary objective of an authentication system is to prevent unauthorized users from gaining access to the system[10].

2.2.2 Authentication Methods

The authentication methods have been categorized into three different types based on something the user knows (e.g. a password), has (e.g. a physical card) or is (e.g. fingerprints)[11].

The first type is currently the most commonly used. A system requires the user to provide specific information such as password or pass phrases to access the system. This method has the advantage of both simplicity and easy implementation. However, passwords often provide an unreliable basis for authentication. The big problem with password-based authentication is eavesdropping[8].

The second type requires physical objects that a user must have to access the system. Examples of physical objects include smart cards and magnetic cards[5][8]. This method provides a higher level of security than passwords alone and also is simple to use.

The third type is advantageous as it may not be easily guessed or stolen. It is using a user's physical characteristics such as a fingerprint or hand geometry and matching them against a profile to grant or deny access[5]. However, the technology required to implement most biometrics methods is very expensive.

2.2.2.1 Passwords

Passwords or pass phrases are predefined words that an authorized user knows and provides to the system for granting access. The passwords or pass phrases may be

assigned by the system or selected by the user. This type of method is one of the most widely used authentication methods. When a user presents the password that matches the password stored in the system for that user, the system grants access.

On some systems, passwords are administratively set to a fixed attribute of a person, such as their birth of date or their email address. Although they are easier to remember, they are often easily guessed. Many systems allow users to select their own passwords that are difficult to guess. They also may be guessable if the imposter guesses enough times. In general, the password should be both easy to remember, but difficult to guess. In fact, any password, no matter how carefully chosen, can be guessed by enumerating all the finite characters sequences until you get the correct password.

There are many real problems with password-based authentication. For example, an eavesdropper might see the password when a user is using it to log in, the password might be easy to guess, or an intruder might read the file where the system stores passwords. Several approaches can be taken to reduce such threats and to prevent unauthorized people from gaining access to passwords. First, people should never write a password down, and should change the password on a regular basis. Second, the system could keep track of the number of consecutive incorrect passwords entered for an account, and when the number exceeds a threshold, "lock" the account and refuse access, even with a correct password, until the system is administratively reset[8]. Third, the user's password file could be encrypted[12].

2.2.2.2 Physical Keys

Physical keys are objects that a user must have in his possession to access the system[13]. The most common is the key that we use everyday to unlock our home or car. In computer and network systems, the three commonly used physical keys are magnetic cards, smart cards, and specialized calculators[5].

A credit card is one example of magnetic cards. It is a piece of non-conductive material with an additional piece of magnetic recording material attached[13][14]. The advantages of using magnetic cards are that they are not easy to forge and they can hold information that is not easily memorized. There are disadvantages to using magnetic cards. First, in order to use the magnetic card technology, the system requires hardware (e.g. card reader) on each access device, such as an access terminal or a physical access path (e.g. a door). Second, the card can be stolen or lost. To improve security, the card must be used with a PIN or password for authentication.

A smart card is a better type of physical key. It is a device similar to the credit card but is capable of processing, storing, and manipulating data. The elements of a smart card are a microprocessor, memory, input/output devices, and a power source[5][15]. Due to the processing capability, smart cards have a lot of applications such as phone cards, vending machines, and road tolls. Smart cards are also being used in cellular phones and satellite TV's. Attempts are now being made to integrate all the applications into a single card. Like magnetic cards, the serious practical problem with smart cards is the need for card readers at every access terminal. But the information stored on a smart card is safer than that stored on a magnetic card because smart cards are more difficult to duplicate and offer substantial protection against eavesdropping.

2.2.2.3 Biometrics

Biometric keys are used in the user authentication process due to their characteristics and recent advancements in technology. Biometric keys provide many advantages over password-based keys or physical keys because they belong to the authorized user and are difficult to reproduce. There are various biometric keys. Some commonly used ones are fingerprint, hand geometry, and retinal prints. The authentication process allows the granting or denying of user system access based on the user's unique physical characteristics. The whole process is accomplished by obtaining an unverified sample from a user and comparing it to a previously authenticated sample. Biometric key authentication is very accurate and very difficult to reproduce. With the rapid advances in technology, biometric authentication is becoming an attractive authentication method.

2.3 Access Controls

Access control is the mechanism used to protect information from unauthorized access. Access control can define not only who or what process may have access to a specific resource, but also the type of access that is permitted[15]. Permissions are defined by the system access control policy. An access control policy basically includes a set of rules that describe the methods in which a user can access the system resource. Various schemes can be used to implement access control and protect system resources, such as a password-based scheme, a capabilities based scheme, an access control list, and protection bits. Only two of these are discussed below.

2.3.1 Password-based Scheme

A password-based scheme is similar to its usage for user authentication. In order to gain access to information (e.g., a file), the user must present the information's password to the system. In this technique, the password for specific information is different from the password for the system. The system manager or the owner of the information originally assigns a password to the information. Then the information's password must be told to the user who is to be given access to the information.

Conceptually, this technique is easy to understand and easy to implement. It also provides a fine grained security level. But it has several problems and is not suitable for most environments today. According to this scheme, users have to remember each password for each specific information they will access. The first problem is that the user needs to remember a large number of passwords. Also, with this technique there is no way to determine who has access to specific information because anyone who knows the password could access the information.

2.3.2 Access Control List

An access control list (ACL) is a table that tells a system which access rights each user has to a particular system object, such as a file directory or individual file. Each object has a security attribute that identifies its access control list. The list has an entry for each system user with access privileges. The most common privileges include the ability to read a file (or all the files in a directory), to write to the file or files, and to execute the file (if it is an executable file, or program). Windows NT[30], Novell's NetWare 5[31], Digital's OpenVMS[32], and UNIX-based systems are among the

operating systems that use access control lists. The list is implemented differently by each operating system.

There are several advantages in using this method. Since a list is associated with each file instead of each user, it is easier to determine who has access to a specific object and easier to change a user's access permission. This technique also has two disadvantages. First, it is very restrictive because a user can only access the objects explicitly named in the list and an object can only accessed by a specified set of users in its ACL. Second, it becomes difficult to update and check all the object's ACLs when objects are changed.

2.4 Database Security

Database security, as a whole, is considered to deal with the confidentiality, integrity, and availability of the data stored in a database system. Confidentiality means information is only disclosed to those users who are authorized to have access to it. Integrity means information is modified only by those users who have the right to do so. For example, an employee should not be able to modify his own salary or change data concerning other payments. Availability means that information and other resources can be accessed by authorized users when needed.

For most environments, the confidentiality and integrity are often taken as a combination. Normally this is the case for systems where incorrect data could result in vast loss. A database may suffer from any of four different types of vulnerabilities[5]. These vulnerabilities are inference, aggregation, data integrity, and Trojan Horses. The following paragraph gives definitions of these terms.

Inference means the derivation of new information from known information. The problem is that the new information may be classified at a level for which the user has no permission. To properly protect a database from inference is not an easy task because inference vulnerabilities allow a user, either authorized or unauthorized, to determine the contents of the data without performing any malicious actions. Aggregation is the result of assembling or combining different tables of data when handling sensitive information. Aggregation of data might result in the dissemination of what would otherwise be considered hidden, or private, information. . Data integrity vulnerabilities allow the unauthorized or inappropriate modification, addition, or deletion of database data. A Trojan Horse is a program that performs a task that a user does not expect and does not want completed[5]. Unlike inference and aggregation, a Trojan Horse attacks the database operations and data.

Several security mechanisms can be used to prevent such vulnerabilities. These mechanisms are often similar to those employed in non-database systems, and they emphasize different applications of cryptography.

2.5 Cryptography

Cryptography is the science of writing messages that no one except the intended receiver can read[15][16]. Cryptography provides stronger methods of authentication. Two examples of using cryptography are given.

A user can encrypt the data on his computer so that even if some people gain physical access to the computer, they cannot access the data. Most web browsers (e.g., Netscape Communicator or Internet Explorer) now support SSL (Secure Sockets

Layer)[17], a cryptographic protocol that encrypts information before it is transmitted over the Internet. Thus, a user can shop online using his credit card number without worrying too much that the number will be stolen.

2.5.1 Public Key Cryptography

Public key cryptography is a system based on a pair of keys. The idea is to use two separate keys: a private key that need not be revealed to anyone, and a public key that is preferably known to the entire world. These two keys are used for encryption and decryption, and the decryption key cannot be derived from the encryption key. All known methods are quite slow, and they are usually only used to encrypt session keys that are then used to encrypt the bulk of the data using a symmetric cipher.

The algorithm could work in two different ways (shown in Figure 2.1). For example, the public key could be used to encrypt a message by someone who has never met the recipient, and only the recipient with the private key could read the message[15][16]. Or the private key could be used to sign a document, and anyone could use the public key to verify the signature[15][16]. The second way is often called a digital signature. Either way, two people do not need prior contact to communicate privately over an insecure channel.

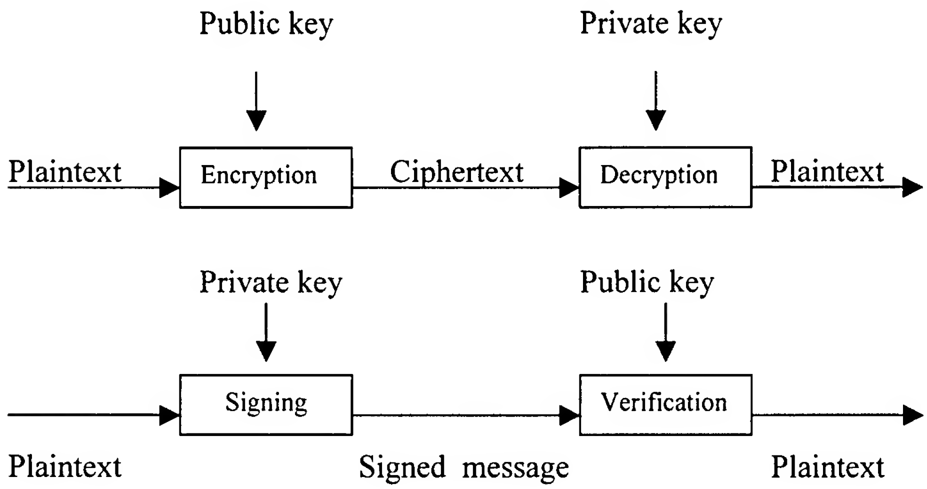

Figure 2.1 Two Methods of Public Key Cryptography

The basic idea is that public key cryptography provides a means by which two ends of the network can trust each other. For example, in a simple client/server application, the client application could send the user's credentials encrypted with the server's public key and send them to the server. Then the server could decrypt the user's credentials and authenticate the user's identity. If someone acquires the encrypted messages by listening in on the entire process and has the server's public key, however, he can not recover either the client's credentials or the server's private key. This offers both confidentiality and integrity for network messages.

In addition to the authentication example described above, public key cryptography also can solve many of the security problems of large, heterogeneous networks. In the proposed software architecture in this thesis, public key based cryptography has been built into **TEAMDEC** to provide user authentication.

Two commonly used public key algorithms, RSA[18] and Diffie-Hellman[4], are discussed below. Detailed descriptions of these two algorithms are given in [16].

2.5.1.1 RSA Algorithm

RSA (Rivest-Shamir-Adelman)[18] is the most commonly used public key algorithm. It can be used both for encryption and for signing. It is generally considered to be secure when sufficiently long keys are used (512 bits is insecure, 768 bits is moderately secure, and 1024 bits is secure, see Table 5.2). The security of RSA relies on the difficulty of factoring large integers. Dramatic advances in factoring large integers would make RSA vulnerable. RSA is currently the most important public key algorithm. At present, 512 bit keys are considered weak, 1024 bit keys are probably secure enough for most purposes, and 2048 bit keys are likely to remain secure for decades. One should know that RSA is very vulnerable to chosen plaintext attacks - a form of cryptanalysis where the cryptanalyst may choose the plaintext to be encrypted[19]. In a chosen plaintext attack, the cryptanalyst not only has access to the ciphertext and associated plaintext for several messages, but he also chooses the plaintext that gets encrypted. Because the cryptanalyst can choose specific plaintext blocks to encrypt, they might yield more information about the key[16]. If the key used to encrypt or decrypt the messages is deduced, the algorithm is broken. The RSA algorithm is believed to be safe when used properly, but one must be very careful when using it to avoid these attacks. Many implementations of RSA are freely available.

2.5.1.2 Diffie-Hellman Algorithm

Diffie-Hellman[4] is a commonly used public-key algorithm for key exchange. It is generally considered to be secure when sufficiently long keys and proper generators are used. The security of Diffie-Hellman relies on the difficulty of the discrete logarithm problem (which is believed to be computationally equivalent to factoring large integers)[16]. Diffie-Hellman is sensitive to the choice of the strong prime and the generator. The size of the secret exponent is also important for its security. Conservative advice is to make the random exponent twice as long as the intended session key. In practice, if the same prime is used for a large number of exchanges, it should be larger than 512 bits in size, and preferably 1024 bits.

2.5.2 Digital Signature

A digital signature is used to verify that a message really comes from the claimed sender. It is completely analogous to a handwritten signature used for authentication. In cryptography, a digital signature is a block of data that was created using some private key, and there is a public key that can be used to verify that the signature was really generated using the corresponding private key. It is fully described in[20]. Digital signatures provide two important functions: authentication and integrity.

The algorithm used to generate the signature must be such that without knowing the private key it is impossible to create a signature that would be verified as valid. Digital signatures can also be used to timestamp documents, a trusted party signs the message and its timestamp with the private key, thus testifying that the message existed at the stated time[16].

A digital signature of an arbitrary document is typically created by computing a message digest from the document and concatenating it with information about the signer and a timestamp. The resulting string is then encrypted using the private key of the signer and a suitable algorithm. The resulting encrypted block of bits is the signature. It is often distributed together with information about the public key that was used to sign it. To verify a signature, the recipient first determines whether it trusts that the key belongs to the person it is supposed to belong to and then decrypts the signature using the public key of the person. If the signature decrypts properly and the information matches that of the message (proper message digest), then the signature is accepted as valid. Several methods for making and verifying digital signatures are freely available. The most widely known algorithm is RSA.

2.5.3 Message Digest

A message digest is also known as a cryptographic hash function[15]. It is basically a mathematical transformation that takes a message of arbitrary length, transforms it into a string of bits, and computes from it a fixed-length number. A cryptographic hash function does this transformation in a way that makes it extremely difficult to come up with a message that would hash to a particular hash value. Cryptographic hash functions typically produce hash values of 128 or more bits. This number is vastly larger than the number of different messages likely ever to be exchanged in the world. Many good cryptographic hash functions are freely available. Well-known ones include MD5[33] and SHA[25].

Detailed algorithm descriptions on MD5, SHA and digital signatures are discussed in[16].

2.6 The Java Security API

The Java security API is a set of packages that are used for writing secure programs in Java. In particular, JDK 1.2 contains substantial security features enhancements: policy-based, easily-configurable, fine-grained access control; new cryptographic services and certificate and key management classes and interfaces[21]. Two major components, JCA and JCE, will be discussed below.

2.6.1 JCA

JCA stands for Java Cryptography Architecture. It was first introduced in JDK1.1 and refers to a framework for accessing and developing cryptographic functionality for the Java platform[22]. It specifies design patterns and an extensive architecture for defining cryptographic concepts and algorithms.

The JCA includes a provider architecture that allows for multiple and interoperable cryptography implementations. The term cryptographic service provider (CSP), or simply provider, refers to a package (or a set of packages) that supplies a concrete implementation of a subset of the cryptography aspects of the JDK Security API[22]. In JDK1.1 a provider contains an implementation of one or more digital signature algorithms, message digest algorithms, and key-generation algorithms. JDK 1.2 adds five more types of services: keystore creation and management, algorithm parameter management, algorithm parameter generation, key factory support to convert between different key

representations, and certificate factory support to generate certificates and certificate revocation lists (CRLs) from their encodings. The JDK1.2 comes with a default provider, named SUN, that implements a few cryptographic algorithms including a number of DSA services, MD5 and SHA-1 message digest algorithms, and X.509 certificates.

2.6.2 JCE

JCE means the Java Cryptography Extension. Sun divided its cryptographic classes into two groups because the U.S. government limits their export. The first group is included in standard JDK1.2 and can be exported without limitation. The second group is called JCE, and is for U.S and Canadian distribution only.

JCE extends the JDK to include API's for encryption/decryption, key exchange, and message authentication code (MAC)[23]. JCE and the cryptography aspects of the JDK provide a complete, platform-independent cryptography API. The algorithms supported in JCE include encryption/decryption, password-based encryption, and Diffie-Hellman key agreement. By employing this package, one can efficiently reduce development time and prevent errors in applications.

The Java security API is used to implement the security features of **TEAMDEC**. Because the API provides extensive support for cryptographic algorithms and protocols, hides a lot of implementation details, and exposes cryptographic concepts, it is suitable for **TEAMDEC**'s design and implementation. A security requirement analysis of **TEAMDEC** is provided in Chapter 3. Detailed descriptions of these algorithms and implementations are provided in Chapter 4.

Chapter 3

Security Issues in TEAMDEC System

The development of distributed computing has recently accelerated toward a system for sharing data, applications, and computing resources across networks. As applications become more distributed, more useful features are introduced, such as those that enable data sharing and information gathering. However, distributed systems also introduce an increased security hazard. Each site could have a security risk similar to that of a centralized system, as well as the problems introduced by connecting to a network. For successful use of the application, one critical element - security - must be considered.

This chapter first gives a detailed description of **TEAMDEC**. Then the system is analyzed with respect to security requirements and the type of security measures required to be taken.

3.1 Overview of TEAMDEC

3.1.1 What is TEAMDEC?

TEAMDEC is a team based intelligent decision support tool, which integrates information from different sources to facilitate decision-making[2][3]. With **TEAMDEC**, people can make decisions using multiple information sources such as scripts from the script database, information from the commercial search engines (e.g., Yahoo, AltaVista) on the Internet, or through interactive real-time audio/video communication (e.g., video

conferencing) with other decision team members. All these features can help people to make better decisions more efficiently, whether working alone or with a decision team.

A key element of **TEAMDEC** is the script database, which can be used to guide team decision-making. The script database enables a user to specify a set of information/actions that should be taken, and to label this "script" with a scenario name. Thus, when faced with the real situation, the user activates the script and follows the desired procedure. For example, a user intends to carry out a discussion with a number of on-line users about the issues of flight safety. The user must first set the option for suggestion acceptance to “On”, which indicates that the user wishes to get action guidance. After that step, the user’s activities are traced. Simultaneously, the system invokes its inference engine to derive timely action suggestions based on the user’s real-time activities in the **TEAMDEC** system, knowledge from the action database and other databases, and rules which are related to predictive judgment, evaluative judgment, and decision making. The system consequently produces advice on possible actions. Generally, the suggestion information is organized in the structure of the script as shown in Table 3.1. The script consists of two scenarios: the development of a discussion group and the group discussion[2].

Develop a discussion group	Open a window for selecting users
	Display the user information
	Select the user and add to the discussion group
	Remove a user from the discussion group
	Confirm and quit
Begin a group discussion	Open a window for group discussion
	Give a topic
	Send an invitation with the topic to group members
	Get agreement replies from members
	Setup communication channels and begin discussion
	Edit the opinion expression and pose it out
	Send an off-line message
	End the discussion

Table 3.1 Components of a Group Discussion Script[2]

The functionality of the scripts is one of the significant characteristics of **TEAMDEC**. This unique feature makes **TEAMDEC** a flexible, useful, decision making tool. From the table, we know that a script is a set of information that is stored in the script database to guide a user's possible actions. Thus the script database is the most important system asset in **TEAMDEC**.

3.1.2 TEAMDEC's Architecture

TEAMDEC is a team-based decision support system, in which a leader makes a decision with the input of a flexible team of people[3]. Figure 3.1 below shows the main components of **TEAMDEC** and their connections.

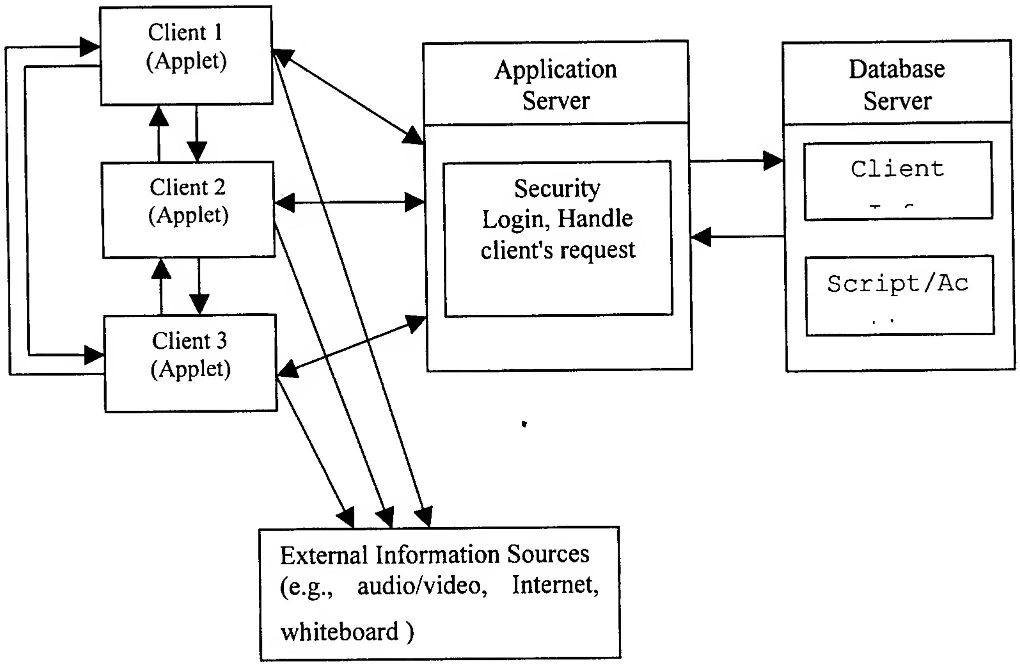

Figure 3.1 TEAMDEC System Architecture

Basically, the system is a multi-user client/server system and employs a three-tier architecture. The system has three components: the applet (also called client), the application server, and the database server. The applet is responsible for GUI display, communicating with other **TEAMDEC** applets, and sending requests (e.g., save request for saving actions, query request for querying about desired scripts) to the database through the application server. The application server is the middle-ware between the applet and the database server. The server is responsible for user authentication and handling client's requests. The database server is responsible for storing and operating system critical data including user information and actions/scripts.

3.2 Security Requirement Analysis

The process of analyzing system security requires the examination of security objectives related to confidentiality, integrity, and availability. The following section gives a detailed analysis of the system requirements in **TEAMDEC**.

3.2.1 Confidentiality Objectives

TEAMDEC is largely dependent on information transmitted among different decision team members and between clients and servers to make it a flexible decision-making system. Without reliable, confidential information, it is not possible to achieve an efficient, better quality decision among decision-team members. Thus, ensuring the confidentiality of the system information and protecting it from unauthorized access becomes the most important task in security analysis. The types of information in **TEAMDEC** are listed below.

The first type of information is that transmitted among different clients. The information would be an invitation, a request, or a response. For example, an invitation message sent by a user to his team members would be: "The discussion topic is Emergency, Would you like to join my discussion group?" The second type of information is the information transmitted between a client and the application server. The information sent by the client to the server would be the client's personal information such as user name, user ID, the client's request code, and the client's action records or scripts. The request code is a digital number that identifies the type of request that the

server will accept. A record or a script is a string consisting of a series of strings, such as time, activity, description of the activity, and name of the action. These strings are concatenated together and describe the user's actions. The information sent back from the server to the client would be the server's response code. The response code is also a digital number that identifies the type of response from the server and the type of scripts retrieved from the database server according to the client's search criteria.

These critical system data are all in plain text if they are not encrypted, which means that when transmitting them from sender to receiver, they will not be secure over the Internet. The data could be accessed by unauthorized people, and could be altered or viewed by a third party. When transmitting the data over the Internet, such a lack of security would be a major flaw.

In addition, if users from inside can get out to the Internet and get valuable information, then without precautions users from outside can get into the local system. This applies not only to the Internet, but also to any system if it allows users to come in from the outside. Interconnection of networks introduces vulnerabilities as a result of network resource sharing with public users. Remote access can leave a system vulnerable to hackers, viruses, and other intruders. The client in **TEAMDEC** is implemented as a Java applet. Although Java can provide several benefits such as platform independence, it also introduces potential security issues.

Because the applet is a program written in the Java language, it can be included in an HTML page. When using a Java-enabled browser to view a page that contains an applet, the applet's code is transferred to the local system and executed by the browser. Thus, anyone could run the applet anywhere in the world and access **TEAMDEC** as long

as he used a Java-enabled browser to view the page. This will not be allowed because only an authorized user should be able to access **TEAMDEC**. To prevent such a situation from happening, user authentication is essential.

In a distributed system such as **TEAMDEC**, a client sends sensitive information to another client or to a server through an insecure communication channel, which may have the following risks. The system data of **TEAMDEC** is highly sensitive. The data could be stolen and disclosed, which would do damage to the whole system and impact the decision-making capability. Someone using the Internet could disguise himself as an authorized user of **TEAMDEC or** could change the information content. For example, an intruder could look at the data packets transmitted on the network and intercept network data sent from client to server or vice versa via network eavesdropping. Eavesdroppers can operate from any point on the pathway between the two communication end points. This is one of the most difficult threats to be detected. Over the Internet, data packets may come through several nodes or even take different paths. For the end point users, there is no way to know exactly what happened during transmission. In the case of wireless communication, the media is accessible to anyone. For mission-critical information transmitted on the Internet by **TEAMDEC**, security measures must be taken to prevent eavesdropping. Data encryption is the only defense against this kind of threat.

The following example could describe the possible attacks mentioned above.

An airplane is in an emergency situation because its landing gear are locked. When the airplane approaches the airport, the pilot calls for help. With **TEAMDEC**, the controller opens the decision script for airplane landing. Following the script prompts, the controller contacts the manufacturer of the airplane and gets possible suggestions. Then

the controller integrates the information from different sources and makes a decision with his decision team. After the possible decision is made, the controller communicates with the pilot and sends him the instructions for a safe landing.

During the whole rescue procedure, there are three possible attacks. First, information from the pilot is stolen or modified. If this mission-critical information is modified, then the controller will not get the correct information and may make a decision that is not suitable for a safe landing situation. Second, the scripts in the database are modified or deleted. If someone modifies the airplane landing script in the script database, for example, then the sequence of instructions from the scripts are modified and the decision team will not make a correct decision. Third, the instructions from the controller to the pilot are stolen or modified. If the important instructions are modified or lost, the pilot can not get the correct instructions and a safe landing will not be accomplished.

Under any of the attacks described above, the rescue task can not be completed successfully and the damage will be great. As seen from this example, security considerations impact the whole system. This example demonstrates the most important objectives of **TEAMDEC**, confidentiality and integrity. For secure, timely, and accurate delivery and receipt of the system data, **TEAMDEC** requires user authentication, access control, and encryption/decryption. These make up the desired security features of **TEAMDEC**.

Different types of user authentication to prevent unauthorized access exist. Different methods may provide different levels of assurance and be used to protect against different threats. In **TEAMDEC**, there is a need not only for confidentiality, but

also for strong user authentication, because **TEAMDEC** is a distributed system over the Internet.

A password-based authentication scheme is a simple authentication method, but it is prone to attack by a user guessing password values. In a relatively low risk environment, it can provide protection for the system from attacks, in which an imposter cannot see, insert, or alter the information passed between the sender and the receiver during an authentication process. But using such a simple authentication method in a distributed network system can only provide weak authentication. The user authentication method in **TEAMDEC**, which will be discussed in the next chapter, uses digital signatures with public/private keys and message digest function for the communication between client and server. It provides a strong user authentication method, and it ensures mutual confirmation of identification.

3.2.2 Integrity Objectives

Integrity is an essential requirement for the proper operation of **TEAMDEC.** The scripts stored in the database are the heart of **TEAMDEC**. By using this critical information, the system helps develop a decision, and provides suggestions such as who should be contacted or which command should be issued when a specific situation happens.

Everyone's role in the decision team environment is unique. For example, one team member might be the team leader, who gets information from different sources and coordinates them before issuing a decision. Another team member might only collect

information from the Internet and report it to the team leader. These different functions may dictate that access rights to the scripts must also be different.

Shared use of **TEAMDEC** by independent team members introduces the risk of unauthorized access to the critical system data and hence compromises the system's integrity. Because in today's networks, disgruntled employees, hackers, and other forms of destruction are common, the threat may come from within the **TEAMDEC** user community or from outside the system. For an outside threat, an unauthorized user could break into **TEAMDEC** and modify some system critical information. For an inside threat, any registered users can access, distribute, and even change valuable information data if proper security measures are lacking. Consider the following examples.

A user of **TEAMDEC** executes some actions such as changing record actions or deleting scripts that he is not authorized to do. This is the kind of attack that breaks the integrity of critical information. A disgruntled user of **TEAMDEC** would retrieve the scripts from the script database and send them to other people who are not related to **TEAMDEC**. This makes confidential information open to others and destroys the security of the system.

The user authentication method can be used to prevent unauthorized access from the entry point of the system, while access control can protect highly sensitive information from being disseminated to users who are not authorized to receive it.

Several access control schemes have been suggested in the literature[24][34][35]. One of these is task and role-based access control for distributed applications[24]. In order to provide a fine-grained access control level to the critical scripts in **TEAMDEC**, a role-based access control method is employed. The access is granted by the user's role

in the system. In the next chapter, the method and its implementation will be discussed in detail.

In addition to the two major security aspects of **TEAMDEC**, confidentiality and integrity, another security objective is availability. This issue is related to denial of access, data loss, or disaster recovery. This is one area that many organizations may overlook[1]. As more and more organizations begin to utilize the Internet for their business, "availability" will be a key requirement for success.

3.3 An Architecture for Achieving a Secure System

As the Internet expands its reach and scope, there are a growing number of computer hackers who attempt to penetrate computers. Computer fraud is becoming more widespread and sophisticated. The previous discussions on security requirement analysis of **TEAMDEC** indicate a critical need to protect system information, such as scripts, records, and users' personal information. The proposed security schemes in this thesis should provide confidentiality and integrity.

3.3.1 Possible System Attacks

The first step in designing a security architecture is to analyze system requirements and identify the possible risk areas in the running environment of the system. Based on previous discussions, we can examine **TEAMDEC**'s architecture again and identify the possible attacks. Figure 3.2 shows the communication among the various parties and the possible attacks.

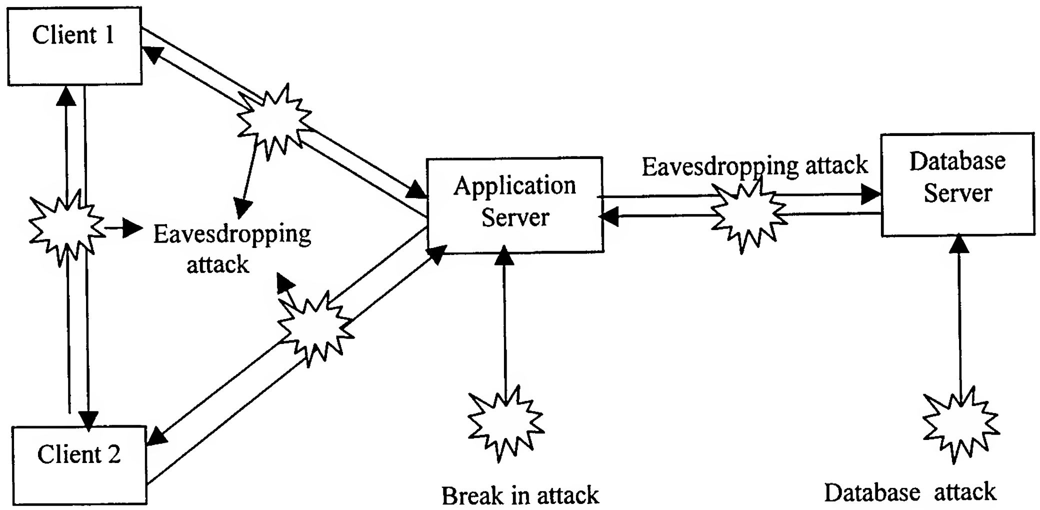

Figure 3.2 System Architecture and Possible Attacks

A *Break in attack* is a type of attack in which the attacker tries to break into the system and obtain unauthorized access to system information. It can be prevented by a user authentication method. An *eavesdropping attack* is a type of attack in which the eavesdropper captures or modifies the information between the two end points of a communication channel. In **TEAMDEC**, this type of attack is possible between the clients, between the client and the application server, and between the application server and the database server. This type of attack can be prevented by using an access control scheme, and/or by using an encryption/decryption method. The *database attack* is a type of attack in which the attacker tries to gain access to the information database directly. An access control method implemented in the application server and in the database server can prevent such attacks.

Once the possible attacks have been identified, the next step is to protect the system from such attacks by using user authentication, access control, and encryption/decryption methods.

3.3.2 Security Methods

TEAMDEC employs a three-tier architecture. A three-tier architecture is a special type of client/server architecture consisting of three well-defined and separate processes including a user interface, a middle tier, and a database management system, each possibly running on a different platform. The user interface runs on the user's computer (the client). The middle tier runs on a server and is often called the application server and actually processes data. A database management system (DBMS) runs on another server and stores the data required by the middle tier[36].

The main drawback to this scheme is the decreased speed compared to a two-tier system in which the clients are communicating directly with the database server. However, the three-tier architecture makes the system more secure. Since the database server can only talk to the application server, it greatly limits the threat of someone connecting directly to the database server and causing damage.

Figure 3.3 shows the security methods proposed in this thesis to prevent the previously described possible attacks.

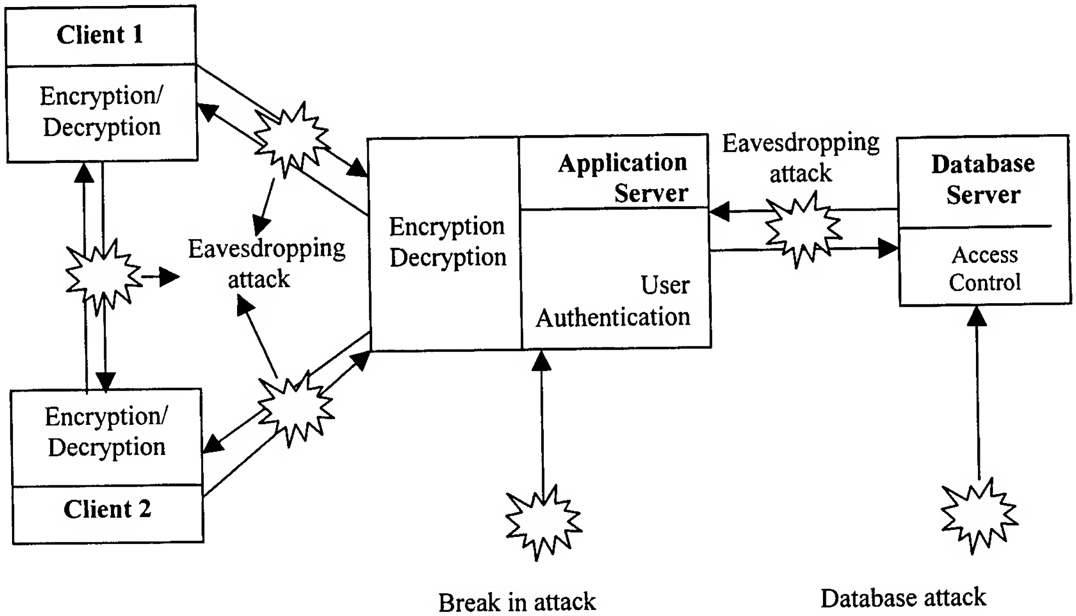

Figure 3.3 TEAMDEC Security Architecture

Figure 3.3 also shows the proposed security architecture for **TEAMDEC**. All the three possible attacks can be protected by the proposed architecture.

The user authentication scheme is based on public key cryptography[15][16][18]. Each new user is first registered by the system administrator and given a pair of DSA keys. The DSA private key is encrypted with the user's password. When the user logs into **TEAMDEC**, he must present his password and private key for the client application to generate a signature and send to the server for authentication. The server verifies the signature by using the user's public key. If the signature has been successfully verified, then the user has been authenticated and will be granted access to **TEAMDEC**.

The encryption/decryption method employed in this architecture prevents an eavesdropping attack. At the beginning of the communication, two end points agree on a session key by using the Diffie-Hellman key agreement protocol[4][16]. The remainder of the communication is encrypted using the session key at the sender and is decrypted using the session key at the receiver. The detailed algorithm description and implementation are presented in the next chapter. Due to the communication between two end points being encrypted, the information on the network is no longer plain text. Although an eavesdropper could capture the message, he can not recover the message.

There are two types of access control implementation. One is the access control scheme that is implemented in the database server by the vendor. The access control list can be configured using a database provided function. The other is proposed and implemented in the application server for fine-grained access control to scripts. This kind of access control is based on the user's position in the system. It can be flexibly configured and updated.

3.4 Summary

This chapter provides an overview of TEAMDEC and its architecture, then gives a detailed security requirement analysis of TEAMDEC. The analysis involves the examination of security objectives related to confidentiality and integrity. It then identifies the three types of attacks in the running environment of the system. Based on the analysis, user authentication, access control, and encryption/decryption methods are proposed to protect the system from such attacks. In the next chapter, a detailed implementation of the three security methods is presented.

Chapter 4 Implementation

In the previous chapter, **TEAMDEC's** security risks are analyzed, and three possible attacks are identified according to its security requirements. In this chapter, a detailed implementation is presented, including the user authentication scheme for preventing break-in attacks, the key agreement protocol for preventing eavesdropping attacks, and the access control model for preventing database attacks.

The implementation is accomplished by using existing Java security packages, specifically, the Java Cryptography Architecture (JCA) and the Java Cryptography Extension (JCE). The choice of Java provides the following advantages. The Java platform is a great development environment and provides a large number of libraries and programs for network application development. Java is portable to nearly every platform, including Windows 95/98, Windows NT, and most UNIX systems. Java also provides a framework and implementations for encryption, digital signature, strong random number generating, key management algorithms and support for encryption including symmetric, asymmetric ciphers in the Java Cryptography Architecture, which makes it an excellent tool for the development of secure applications. Java also enables software reuse and integration capabilities because of its object model.

4.1 User Authentication

User authentication is implemented in **TEAMDEC** to prevent unauthorized users from stealing confidential system information not intended for their eyes and modifying and executing scripts stored in **TEAMDEC.**

Through the user authentication method, the system can assure that the remote user is, in fact, an authorized user. Passwords are a simple solution to authentication; they are easy to implement, but they are not considered very secure, especially when people choose easy-to-guess passwords, or write down passwords in obvious places. A public key based authentication scheme, which is used in this project, is a stronger form of authentication. The whole authentication procedure including key generation and key distribution is outlined below.

(1) Prepare public/private key pair

In **TEAMDEC**, a new user first must be registered. The **TEAMDEC** system administrator generates a pair of public and private keys for each user using the DSA algorithm[20].

(2) Encrypt the user's public key

The user's DSA private key is encrypted with the user's password. The name of the encryption algorithm implemented in JCE is PBEWithMD5AndDES. PBE stands for passphrase-based encryption. PBEWithMD5AndDES is a particular variant of PBE; a MD5 message digest is used to digest the passphrase. The digest value is then used as a DES key. The detailed algorithm is described in PKCS#5, a document published by RSA Data Security, Inc[12].

(3) Client generates signature

Upon logging in, the user is prompted for his user name and password. The password is used to decrypt the user's private key. The client generates a timestamp and a random number. Then the client creates a signature using this data and his private key. After the digital signature is generated, the client sends this information to the server for verification. Figure 4.1 shows the method[7] on the client side:

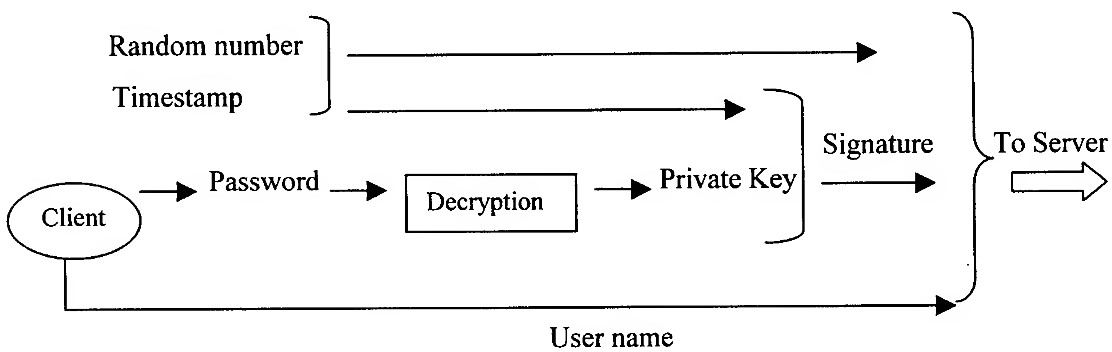

Figure 4.1 User Authentication Method - Client Side

(4) Server verifies signature

After receiving the information from the client, the server retrieves the user's public key according to the user's user name. The server verifies the signature with the client's public key and decides either to allow the user into the system or deny access.

A signature provides two security services, authentication and integrity. Recall from Chapter 2 that a signature is a message digest that is encrypted with the signer's private key. Only the signer's public key can decrypt the signature, which provides

authentication. If the message digest matches the decrypted message digest from the signature, then integrity is also assured.

The name of the algorithm used to generate the message digest in JCA is SHA. SHA stands for the Secure Hash Algorithm that was developed by the National Institute of Standards and Technology (NIST)[25]. Figure 4.2 shows the method[7] on the server side.

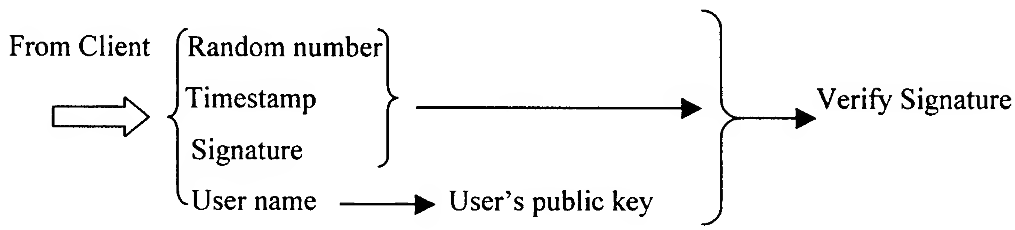

Figure 4.2 User Authentication Methods - Server Side

Safely maintaining and distributing the private/public key files is the most important task. Usually, it involves saving the private key file on a removable media, and carrying it when logging in. Detailed discussions on public/private key security and a possibility of storing the private key file on a smart card are presented in Chapter 5.

4.2 Data Encryption to Prevent Eavesdropping Attack

In **TEAMDEC**, communication among clients, or between client and server are on an insecure medium, the Internet. It is not hard to eavesdrop because data is sent in plain text over the network. In order to guarantee safe communication between different clients and between client and server, cryptography must be added to the system, providing authentication for each end of the conversation and encryption for the

communication itself. A common way to protect information is to encrypt it at the sending end and decrypt it at the receiving end.

The Diffie-Hellman (DH) key agreement protocol[4] is employed in **TEAMDEC** to secure conversations on networks. At the beginning of the conversation, each end point agrees on a session key that will be used to encrypt each data packet sent between them. The remainder of the conversation is encrypted using the session key. The following procedures show how the protocol works between two communication end points, called Client A and Client B. The whole key agreement procedure is presented in Figure 4.3.

(1) At the beginning, create new DH parameters - base and modulus.

(2) Client A creates his own DH key pair using the DH parameters above. Then he executes Phase1 of his version of the DH protocol. He encodes his public key and sends it to Client B.

(3) B has received A's public key in encoded format. He creates a DH public key from the encoded key material. B gets the DH parameters associated with A's public key. He uses the same parameters to generate his own key pair. B executes Phase1 of his version of the DH protocol and encodes his public key, and sends it over to A.

(4) Client A uses B's public key for Phase2 of his version of the DH protocol. Before he can do so, he has to create a DH public key from B's encoded key material.

(5) B uses A's public key for Phase2 of his version of the DH protocol.

(6) At this stage, both A and B have completed the DH key agreement protocol. Each generates the (same) shared secret.

During the subsequent conversation, each end can use the generated secret key to create a DES[26] key, which can be used to encrypt their messages. Although someone is able to hear the entire exchange between A and B, he will not know the shared secret and subsequent communications between them.

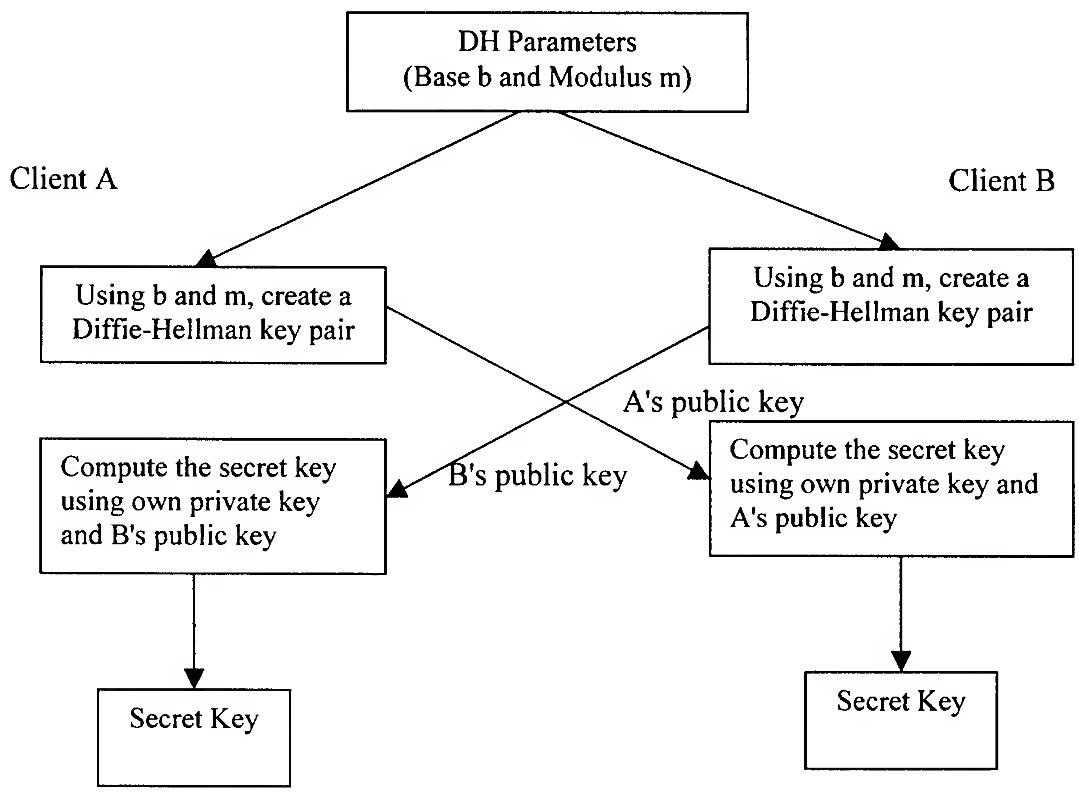

Figure 4.3 Key Exchange between Client A and B

This key agreement protocol can easily be expanded to include three or more participants. For example, if A, B and C participate in a communication, imagine them sitting around a table. Each one picks DH parameters and computes his own DH key pair.

Then each one passes his public key to the person sitting to his right. Thus, each person can calculate the secret value based on the other person's public key and his own private key. If there are 5 participants, 4 exchanges of information are required before the secret value can be calculated[7]. During the whole procedure, five session keys will be calculated that all of these have the same value. The Diffie-Hellman algorithm is implemented in JCE.

4.3 Script Access Rules

4.3.1 User Classification

In many systems, misuse of the administrative procedures could corrupt the system data or deny service to users. In **TEAMDEC**, measures are taken to prevent such things from happening. The system decides whether to allow procedures based on the user's identity, the system scripts' attributes, and the type of operation the user is attempting. In **TEAMDEC**, users are divided into two categories: System Administrator and General Users.

(1) System Administrator

The administrator is a trusted user, authorized to perform system management and maintenance functions essential to the smooth and secure running of the system. These functions are not available to the general user; only the administrator may access them through a separate administration program. The **TEAMDEC** system administrator has exclusive control over the registered user database and scripts database. The administrator has the following responsibilities:

a. Setting up a new user's account

To establish a user account, the administrator must run the system administration program, type certain items, such as user name, user ID, password, user position, user position ID, and group ID to describe the new user, and create an entry in the registered user database and public/private files, when placing the group ID in the user database asserts that the user is a member of the specified group.

b. Deleting an existing user's account

When the user leaves the organization or ceases to require access to **TEAMDEC**, deleting the inactive account improves security. To do this, the system administrator may run the administration program and remove the entire entry that defined for the user.

c. Setting up user groups

To create user groups, the administrator needs to run the administration program, type the group name, the group ID, and a list of names of the users who are authorized to be members of this group, and then place an entry in the group database.

d. Deleting user groups

A group is deleted by removing an entry from the group database.

(2) General User

When a user logs into the system, the user needs his user name, user ID, group ID, and password for authentication. That means the user can only work in one group at a time, even though he may be a member of several groups.

The user database is used to hold information about registered users of the system. Each entry in the user database includes each user's login name, user ID, position, position ID, and group ID. The user database is totally controlled by the system administrator.

Each user must be a member of at least one group and can be a member of several groups. If one user is a member of several groups, the administrator may need to place more than one entry in the user database for this user. In this situation, the system treats the user as different users.

4.3.2 Script Access Rules

Scripts are the critical data in **TEAMDEC**. Each script has several associate attributes that are related to security. These attributes specify the script's access control level. In **TEAMDEC**, the system administrator will specify different permissions for different users and groups. The primary reason is to identify those who can read the script, who can modify the script, and who can execute script, thus, efficiently preventing unauthorized use of the system data and preventing database attack. The following paragraphs discuss this point in detail.

4.3.2.1 Access Control List

An access control list (ACL) is a table that specifies which permission each user has to a particular system object. In **TEAMDEC**, the system objects are the scripts. Each script has a security attribute that identifies its access control list. The list has an entry for each system user with access privileges.

4.3.2.2 Permissions on a Script

The three common permissions on each script are as follows:

Read Permission: The permission to display the name, commands, and description of the script in a table, regardless of whether the user has permission to access the script.

Modify permission: The permission to change the script's name, edit, and delete the script only if the user or the group has appropriate privileges to do so.

Execute permission: The permission to execute the commands of the script only if the user or the group has appropriate privileges to do that.

An access control list is associated with each script. Each access control list has one or more access control entries (ACEs) consisting of the name or ID of a user or group of users. The user ID is assigned according to the user's role in the system. For each of these users, groups, or roles, the access privileges are stated in a string. The system administrator creates the access control list for each script.

Table 4.1 shows a script table. For simplicity, the table does not list all the columns in the script table. Other items, such as Sub Command and parameters, are not listed.

Time	User ID	User Name	Command	Description	Script Name
4/12/99	alice	Alice	Group Discussion	Group Discussion session	Script a
5/03/99	bob	Bob	Send Notice	Send online notice to alice	Script b

Table 4.1 Script Table

The first column is the script name and the second column is the name of the access list. In this three-entry table, each entry in the table specifies the access control list for the script. The system would look at the access control list and determine whether the user who made the request had access privilege. In Script b, for example, the access privilege is defined in ACL2.

Though it is possible to put all the data into one table, it is not logical to do this all of the time. For example, the access control list information could be added in table1; however, the purpose of the script table is to store data on scripts. The solution is to create another table, called Table 4.2, which will contain information about the specific access control list name and associate it with Table 4.1. Table 4.2 shows a table that tells the access control list about scripts.

Script Name	Access Control List Name
Script a	ACL1
Script b	ACL2
Script c	ACL3

Table 4.2 Script Access Control List

Table 4.3 is another table that shows the content of an access list for each script. Suppose this table shows the content for ACL2. Each entry in the table determines the privileges for each system user.

User ID/ Position ID	Permission to read	Permission to modify	Permission to execute
bob	Read	modify	execute
alice	Read		execute
System			execute

Table 4.3 Access Control List Content

In this three-entry ACL example, before reading, modifying, or executing the script, the system would look at the list and determine whether the user who made the request had the access privilege. The ID bob, for example, could read the script or modify and execute it. But the user whose ID is alice could read the script or execute it, but would not be allowed to modify it.

As seen in the previous example, the three tables are related to each other. Table 4.1 contains a column that has the script name. This script name also appears in Table 4.2, which relates to Table 4.3. Table 4.3 lists the content of the access control list. Suppose a user whose ID is Tom needs to access Script b. The system would look at Table 4.2 first and identify that ACL2 specifies the access rules for Script b. Then the

system scans every row in Table 4.3 and tries to find a match. If there exists a corresponding entry in Table 4.3 that matches the user's ID, then the system will grant Tom access privilege to Script b. In this example, the system cannot find an entry in Table 4.3, so Tom's request to Script b is denied.

4.4 Database Protection

In addition to the three measures discussed above, **TEAMDEC**'s database server must also be considered for security concerns. As the repository for critical and sensitive information of **TEAMDEC**, a secure database server is the key technical component in addressing the overall security requirements of **TEAMDEC**. Although network services and encryption devices also provide important measures, the database server is chiefly responsible for processing the most valuable and vital portions of the whole system.

TEAMDEC employs a three-tier architecture, adding a middle application server between the client and the database server. The rationale for this architecture is to isolate the database server for security. This kind of architecture introduces four advantages. First the database server can only handle a limited number of connections. The middle application server can have several clients on one side, while using only one connection to the actual database server, thus reducing the likelihood of breaks-ins into the system data repository. Second, moving the access-control list from the database server to the middle application server will further secure the database server, so that only certain users can access certain databases based on the privileges the system gives them. Third, the database server can be physically isolated. Finally, using a commercial off-the-shelf

database package that has more security mechanisms can further improve system security.

4.5 Summary

Based on the analysis of TEAMDEC's security risks, this chapter goes into more depth on the implementation of the security architecture of TEAMDEC. The three security methods, the user authentication scheme, the key agreement protocol, and the script access control model, are presented. Finally, database protection is discussed for security concerns. In the next chapter, the security implementation of the system is evaluated and possible suggestions are provided for future development.

Chapter 5 Security Evaluation

Security evaluation is one of the important stages in the whole security architecture development. With security evaluation, the strengths and weaknesses of the implementation can be identified, and the quality of software architecture can be determined. Thus, the system can be continually enhanced in the future.

This chapter analyzes the security implementation, which is described in the previous chapter. The analysis is based on functionality and the ability to prevent different types of attacks. In addition, the advantages and disadvantages of the security algorithms are evaluated, and possible improvements are suggested for future developments.

5.1 User Authentication

5.1.1 Functionality

Public key based user authentication has been implemented in **TEAMDEC** to prevent unauthorized access. The obvious advantage of this scheme is that it is more convenient than secret key cryptography, because it is not necessary for two parties to authenticate each other by sharing a secret key. In addition, one of the most important aspects of public key cryptography is that it enables digital signatures, which are used for user authentication.

However, the disadvantage of the public key based method is the performance penalty incurred. As noted in Chapter 4, to use this method, public/private keys must be

generated, the private key needs to be encrypted and later decrypted, and the signature must be generated and verified. The cost of this method is affected by the key size. Table 5.1 shows the time needed for the whole authentication procedure. These results are tested on a Pentium II 450MHz system with 128M memory running the Windows 98 operating system. The time required to generate DSA Key Pair is obtained by running the system administration program in which a pair of DSA keys are generated for each user. The time required for client signing is observed when a client logs into the system. It includes the following periods: the time to generate a timestamp, the time to generate a random number, and the time to generate the signature using his private key. The time required for server verifying is examined at the server side when the server receives the information and verifies the signature.

Key Size (# of bits)	Generating DSA Key Pair	Client Signing	Server Verifying
	Time (*ms*)		
512	33400	33120	33740
768	33450	33170	33890
1024	33560	35700	36410

Table 5.1 Testing Results

Public key algorithms are based on the difficulty of factoring large numbers that are the product of two large primes[16]. Factoring large numbers is difficult, but with the advances in computer technology and mathematics, factoring large numbers is requiring less time than in the past. Table 5.2 lists some results from[16].

# of bits	Mips-years required to factor

512	30,000
768	$2*10^8$
1024	$3*10^{11}$
1280	$1*10^{14}$
1536	$3*10^{16}$
2048	$3*10^{20}$

Table 5.2 Factoring Using the General Number Field Sieve

Mips-year: a one-million-instruction-per-second (mips) computer running for one year.

The table above shows that when the size of the key only increases once or twice, the time to factor increases dramatically. Thus, the length of the key plays an important role in the security of public key based authentication method. It is very difficult to determine which key size is appropriate. The shorter the key size, the likelier it is to be factored and attacked. The longer the key size, the more difficult it is to attack, but the greater the computation time needed to generate key pairs and to perform signing and verification.

From the testing results in Table 5.2, large key length doesn't impose excessive overheads on computing time. When the key length increases from 512 bits to 1024 bits, the key generating time, client signing time, and server verifying time only increased 0.48%, 7.8% and 7.9%, respectively. But the security benefit is very impressive: the Mips-years required to factor increased from 30,000 to $3*10^{11}$.

5.1.2 The Difficulty of Attack

Another issue in evaluating an algorithm is the algorithm's ability to resist different types of attacks. The figure below shows the entire authentication procedure.

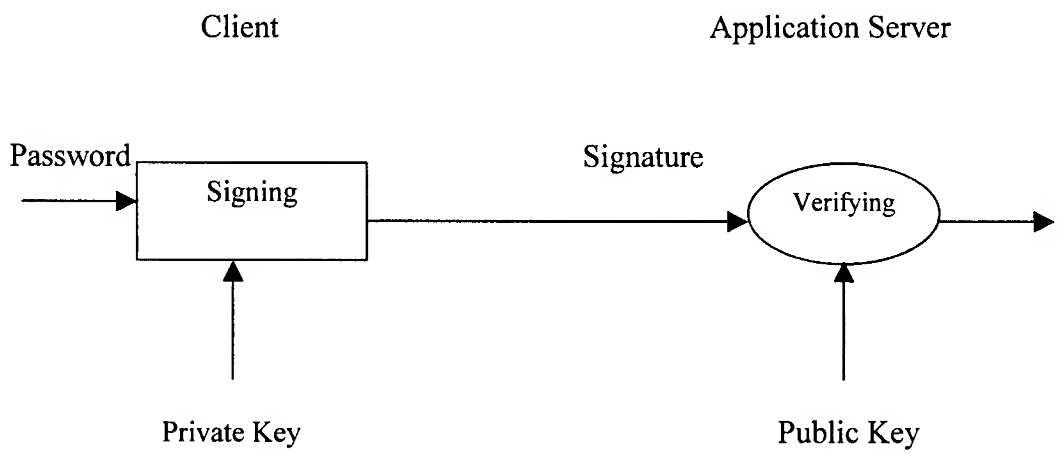

Figure 5.1 Operation of the Authentication Algorithm

Consider the following types of possible attacks.

First the attacker gets only the user's password. Suppose the user's password is stolen or guessed, can the attacker break into **TEAMDEC**? This possibility does not exist, because the authentication procedure depends not only on the user's password, but also on the user's private key. Without the private key, all the following authentication procedures can not be performed. This is the obvious advantage of the public key based authentication method over the traditional password-based authentication method.

Second the attacker gets the user's private key. If the attacker gets the user's private key, can the attacker break into the system? At this time, the possibility of breaking into the system is greater than in the previous attack. Because the attacker has stolen the user's private key, he may try different methods to get the user's password, and then successfully break into the system. Usually people choose easy-to-remember

passwords. For example, some people choose their birthdays or other relevant personal information as passwords. Sometimes people write down their passwords and keep this record on a little piece of paper in their wallets. All these habits give the attacker opportunities to attack the system. There is a type of attack called "dictionary attack"[16] because the attacker uses a dictionary of common keys. By using this system, 40 percent of the passwords on the average computer can be cracked[16] . Hence, how to store and protect the users' private keys becomes one of the most important issues in the **TEAMDEC** to improve system security.

As seen in Chapter 2, the physical and electrical properties of the smart card make it an ideal medium for safely storing private keys. If the user's private key is on a smart card, and the private key never leaves the smart card, then the system would never be in a situation where it is easily compromised. With the smart card the private key is portable and can be used in different places no matter whether the user is at work, or at home. In addition, storing the private key in a smart card is more secure. For example, if the private key is stored in a floppy disk and protected by a password, then the private key file can probably be attacked by a "dictionary attack"[16]. But if the private key is stored in a smart card, the card will normally lock itself up after several consecutive bad password attempts. Thus "dictionary attack" is no longer a feasible way to get the private key. However, any security system, including smart cards, is breakable. There always exists a trade-off between cost and performance. Choosing a smart card to protect a private key depends on the cost of the equipment and the security level to be achieved.

Third, the attacker gets the user's public key. If this situation happens, the attacker has the user's public key, but it does not do him any good. Based on the theory of public

key cryptography[4][15][16], it is computationally hard to deduce the private key from the public key, because public key cryptography relies on one-way functions; functions which are easy to calculate but hard to reverse without prior knowledge. Factorization is one example of a one-way function. It is often difficult to factor large numbers, but easy to verify a factorization. For example, it is harder to factor 6231 than to verify that 67*93 = 6231. With the development in computer technology and networks, no one can predict advances in mathematical theory. The table below shows the number of decimal digits factored [16] in different years.

Year	# of decimal digits factored	How many times harder to factor a 512-bit number
1983	71	> 20 million
1985	80	> 2 million
1988	90	250,000
1989	100	30,000
1993	120	500
1994	129	100

Table 5.3 Factoring Using the Quadratic Sieve

This is a very fast-developing field. Recently, RSA Data Security, Inc. published the following information[27]:

"On February 2, 1999, a group of researchers completed the factorization of the 140 digit RSA Challenge Number. The work was accomplished with the General Number Field Sieve.

Sieving was performed on about 125 SGI and Sun workstations running at 175 MHz on average, and on about 60 PCs running at 300 MHz on average. The elapsed time was one month and the total amount of CPU-time spent on sieving was 8.9 CPU years."

With the advances in mathematical theory and computer technology, computational algorithms, once considered infeasible to break, may be breakable in the future.

5.2 Secure Communication

Secure communications between two end points of an unsafe communication channel are achieved through the Diffie-Hellman key agreement protocol[4] which generates a session key first, and then encrypts the remainder of the conversation using that session key.

Although using the Diffie-Hellman key agreement protocol[4] is efficient for key agreement and eliminates the need for prior communication between users, the possibility of attacks still exists.

If an eavesdropper sits between the two parties and is able to hear the entire key exchange procedure, will he be able to know the value of the secret key? This question involves the security of the Diffie-Hellman algorithm[4]. During the entire key exchange, the two parties exchange their DH public keys. From the previous discussion, we know it is computationally hard to deduce the private key from the public key. If the time needed to figure out the private key from the public key is too long, the session maybe already be finished. Thus, the attacker will not succeed.

If an eavesdropper sits between the two parties and is able to get the encrypted message, will it be hard for him to recover the session key? This question involves the security of the DES algorithm. DES stands for Data Encryption Standard, which is described in NIST FIPS 46-2 [26]. According to the document, DES has a 64-bit block size and uses a 56-bit key during execution (8 parity bits are stripped off from the full 64-bit key). When using DES, there are several practical considerations that can affect the security of the encrypted data.

In our application, a different DES key is generated for each session, and a secure key agreement is provided by the Diffie-Hellman algorithm[4] that will improve the security of DES. Despite the efforts of researchers over many years, no easy attack on DES has been discovered. There is a fact stated in[27]:

> "Most recently, Distributed.Net, a worldwide coalition of computer enthusiasts, worked with the Electronic Frontier Foundation's (EFF) "Deep Crack," a specially designed supercomputer, and a worldwide network of nearly 100,000 PCs on the Internet, to win RSA Data Security's DES Challenge III in a record-breaking 22 hours and 15 minutes, beating the previous record of 56 hours".

Clearly, for a session this kind of attack is normally impractical. But if a session is recorded, the break in opportunity now exists because the attacker could decrypt the key in the future and thus get the secret messages between the two parties.

5.3 Database Server Issues

The database server in **TEAMDEC** system plays an important role, since the primary goal of **TEAMDEC** is to provide better decisions based on the past actions and

scripts stored in the database. Ideally, database security should enable the system to have confidence that its data repository will provide the information requested and expected, while denying accessibility to those who have no right to it. However, issues exist relating to the database server, in particular, speed and security assurance.

The database server used in **TEAMDEC** is Mini SQL[28]. Mini SQL is a lightweight database server for both large and small data sets. In addition to the basic functions it provides for manipulating data, the Mini SQL server also provides functions to control unauthorized access through an access control list. It does not support encrypted connections, however, and thus is still vulnerable to security breaches. Unlike some commercial database products, the Mini SQL server does not support powerful and flexible security mechanisms to provide assurance. To prevent possible attacks on the database server, and to improve confidentiality, integrity, and availability, it is better to replace the current Mini SQL server with commercial products such as Trusted Oracle 7[29] from Oracle Corporation in the future.

5.4 Summary

This chapter gives an evaluation of the security implementation. The evaluation procedure is based on two factors: functionality and the ability to prevent different types of attacks. In addition, the advantages and disadvantages of the security algorithms are evaluated and possible improvements are suggested.

Chapter 6 Conclusion and Contributions

With the growing popularity of the Internet, network security is a foremost concern for many applications. With proprietary technology, a network security solution can secure the application running on an unsafe medium, such as the Internet.

6.1 Conclusion

The software architecture proposed in this thesis enables the secure and efficient operation of **TEAMDEC:** a team-based decision support system. Based on the system's requirements and architecture, three types of possible attacks to the system are identified, and a security solution is proposed that includes user authentication, secure communication, and script access control. The implementation of these features reduces security risk, improves the overall system security, and effectively uses the valuable system information data. Several advantages are provided by this architecture.

First, **TEAMDEC** demands a higher level of security than a simple distributed application. To guarantee that only an authorized user can access **TEAMDEC**, a public key based user authorization scheme is employed. The scheme can ensure that the remote user is, in fact, an authorized system user. In addition, with a digital signature, the scheme provides two security services, authentication and integrity.

Second, the Diffie-Hellman key agreement protocol[4] is employed to achieve secure communications among team members in such an open network environment. By

exchanging keys and computing the shared secret key, the two parties can exchange the keys and messages over an unsafe communication channel.

Third, a generic script access model is defined to provide integrity and secrecy of scripts in the **TEAMDEC**. The model allows fine-grained control access to individual scripts and their attributes that is based on the individual's role in the system.

The implementation is accomplished by using existing Java security packages, specifically, JCA and JCE. By using these commercial Java security packages, it is fast and efficient to develop the security features of **TEAMDEC**.

The development of appropriate security measures for TEAMDEC necessitated the evaluation of security performance of the software. While the options adopted for TEAMDEC appear appropriate, it is important to note that computer technologies advance every day. As a result, algorithms or applications currently considered secure may not be secure in the future. The evaluation procedure is valuable and it can be used to maintain and improve the system in the future.

6.2 Contributions

The contributions of this research are twofold. First, the desired collaborative features of TEAMDEC have been implemented. These features include interactive, simultaneous communications among team members of TEAMDEC and real-time search and integration capability. The most important contribution is that the implementation of the **TEAMDEC** script system. The system is able to record and track the user's actions and provide the action suggestion scripts. The second area of contribution of this research and specifically of this thesis is that the security architecture is proposed and

implemented. These security features enable the secure operation of TEAMDEC and thus improve the quality and efficiency of TEAMDEC's decision-making capability.

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Appendix C

Teamdec Quickstart Reference

Communicating with Group Members

Purpose: Enables online communication with team members, allows user to hold interactive discussions, send notices.

Step 1: Create a communication group.

> Select "Tools."
> Click on "Select Communication Group."
> Highlight desired group members on the user list. The name of the group members selected will appear in the left frame.

Step 2: Hold a group discussion

> Select "Group Discussion."
> Type your discussion topic on the "My Topic" field.
> Click on "Invite" to notify group members of the discussion about your topic.
> Once all desired group members are in the "chat room," click on "Begin."
> Type your message in the "Type your words here" field.
> Click on "Send" to send the message to other group members.
> Click on "clear" to erase the display of prior discussion.
> To end the discussion, click on "Exit the Group."

Step 3: Send a notice

> Select "Send Notice"
> Type your message in the field on the notice screen.
> Click "Send" to deliver message to your communication group.

Surfing the Net with Teamdec

Purpose: Enables user to obtain information from the Internet using any of the Internet search engines (e.g., Lycos, Yahoo).

Step 1: Search the net

> Go to "Tools" (or to the WWW icon).
> Click "Search the Web"
> Type in key words, press "OK" to initiate search.

Step 2: Go to a particular website

> Go to "Tools."
> Select "Open Browser," and then select "Simple."
> Type in URL (site address). Press "OK."

Using scripts with Teamdec

Purpose: Enables user to store sequences of actions for future reference and use, and to send stored sequences as scripts to other users, such as for training.

Step 1: Record a script.

Select "Options" from the main menu.
Click on "Record ON" to record all subsequent actions. (When you are done creating a script, click on "Options" and "Record OFF.")

Step 2: Edit a sequence of actions (only after you have recorded a sequence!)

Select "Script," then "Edit/Save Recorded Data."
Click "Save" to save the new record in the record edit window.
Give the script a unique name.
Click "Close" to exit the screen.

Step 3: Search for a stored script (set of recorded actions)

Select "Script," then select "Load/Edit/Execute" stored script.
In the Script Window, click "Load."
In the Script Search window, type in the identifying information (e.g., script name, user id), and click on the appropriate boxes. (Try the script titled "practice" for fun!)
Click "OK" to run the search.
In the Search Result window, highlight the desired actions.
Click "Close."

Step 4: Run a script

Select "Script" from the main menu.
On the script window, select "Script" and "Load" to load the desired script.
Enter the script name and click on the appropriate descriptive box at the bottom.
Press "Okay" to find the script.
In the Script Edit window, select Script.
Select Execute to run all aspects of the stored script.

Note: to execute just one aspect of a script, highlight the selected aspect and doubleclick. Click "Execute" to run the selected script.

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